EVALUATION OF CRUSHED COCONUT SHELL AS FILTER MEDIA IN DEEP BED FILTERS

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CERTIFICATE

Certified that the work presented in the thesis entitled 'Evaluation of Crushed Coconut Shell as Filter Media in Deep Bed Filters' prepared by Salome Varghese,P has been carried out under my supervision and it has not been submitted elsewhere for a degree.

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Utilization of locally available materials as media in single media filters has been tried by engineers and researchers in the past. Literature shows that crushed coconut shell may be a substitute for sand in single media filters. In the present investigation laboratory scale studies were conducted to determine the potentiality of crushed coconut shell as a filter media under different pretreatment conditions and flow rates.

The concept of 'filterability number' was applied in the preliminary screening tests to obtain the optimum combination of media-suspension and extent of pre-treatment to be given to the suspension. The results obtained from this study were used in conventional column studies. The feasibility of direct filtration for treating moderately turbid waters was studied using crushed coconut shell as the filter media.

The results of the experiments showed slower development of head loss in crushed coconut shell media filter than in sand filter for raw water, conventional and direct filtration. The total head loss in shell media filter was

found to be one third to half of that in a conventional sand filter. The effluent quality in a shell media filter was comparable to or better than that in a sand filter. The low headloss development in a shell filter is attributed to the high porosity of the bed. Some attempts were made to understand the removal mechanism which led to the better performance of a shell media filter. It is felt that eventhough the bed porosity is high the pore sizes may be small enough to trap the suspended particles thus enhancing removal.

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1. INTRODUCTION

Water adequate in quantity and safe in quality is essential for the very existence of human life. Supply of adequate potable water is assuming extremely difficult dimensions particularly in developing countries. The status of water supply in rural areas is all the more bleak. According to World Health Organisation survey (WHO, 1977) the urban and rural population served by piped water supply in India were 48 percent and 18 percent respectively in 1975. The major problem facing the implementation of the programme of supplying potable water to all the people is the high cost of treatment of water and distribution. Besides, the cost of supplying water increases as the density of population decreases which is the case in villages normally. Chaudhuri and Bhattacharya (1979) report that piped water supply would be economical only if the population density is more than 30 per acre.

In order to foster better water supply programmes in developing countries, United Nations at its Water Conference at Mar Del Plata, Argentina in 1977 decided to observe the decade (1981-90) as 'International Water Supply and Sanitation Decade'. It is expected that at the end of this decade all rural and urban population will be served with adequate safe drinking water. This means water supply to nearly 10 million people per year. In rural areas the problem is still worse. By the end of this decade 500 million people will have to be provided

with safe drinking water. The expected cost of attaining this goal has been estimated to be Rs. 300 crores per year (Deodhar, 1980). In order to achieve the mammoth task of providing potable water to all it is essential either to develop newer technology of low cost water treatment or modify the existing water technology. The rural population which is accustomed to consuming even turbid waters may not put so high a standard of aesthetics as the urban community does and hence can be served with even slightly turbid water provided it is free from pathogenic organisms.

Removal of suspended and colloidal particles and destruction of pathogenic microorganisms are the main objectives of treatment of surface water supplies. Filtration of water has been practised for the past eighty years for the removal of suspended and colloidal particles and as a pretreatment for effective disinfection. The quality of the raw water and the water quality standards acceptable to the community decide the extent of pretreatment required prior to filtration. In the conventional treatment of water, either plain sedimentation or coagulation and flocculation followed by sedimentation constitute the pretreatment processes.

In the last decade attempts were made to simplify the treatment of low turbidity waters by adopting only coagulation and flocculation prior to filtration. The results of the studies conducted in this respect were encouraging as water of acceptable

quality was produced reducing the cost of treatment of water considerably. Direct filtration, as it is designated, has been implemented in several municipal water works treating water from reservoirs which has low turbidity.

Rapid sand filters have been in vogue for several decades. The cost of operation of a rapid sand filter depends to a great extent on the frequency of backwashing required, which in turn is normally governed by the buildup of head loss in the filter media. Sand is normally used as the media in filtration. Different materials have been tried as filter media on laboratory scale studies with a view to achieving lower head loss development in the filter without compromising with the effluent quality to reduce the operational cost.

In the present investigation the potential of crushed coconut shell as filter media is evaluated. The specific objectives of the study are: (1) to employ the concept of 'filterability number' as an effective laboratory tool before conducting long and cumbersome conventional pilot studies to evaluate crushed coconut shell as a filter media. (2) to check whether filtration without pretreatment could be employed in treating water having moderately low turbidities using crushed coconut shell media to produce water with turbidity levels within acceptable limits. (3) to compare the performance in terms of effluent quality, head loss development and service time

of both sand and crushed coconut shell media for conventional and direct filtration under varying operational conditions.

2. LITERATURE REVIEW

Filters were introduced for the clarification of surface waters in early nineteenth century in U.K. Filtration plants of nineteenth century consisted mainly of open sand beds of run of bank sand through which the rate of filtration was considerably low. Rapid sand filters were introduced to municipal water treatment systems in U.S.A. in the beginning of twentieth century. During the past few decades researchers and practising engineers have been working towards attaining faster rates of flow and also making the system more economical. Considerable effort has also been put in by researchers to understand the process of filtration, but the process is not yet fully understood.

2.1 Types of filters

2.1.1 Slow sand filters

Slow sand filters are normally limited to low turbidity waters not requiring chemical pretreatment. The characteristic features of slow sand filters are low rates of filtration (0.125 to 0.25 $m^3/m^2/hr.$), uniformity of media throughout the bed depth, small effective size (0.25 to 0.35 mm) and large uniformity coefficient (2 to 3) and removal of impurities at the surface of the bed. The removal is mainly due to the formation of a surface mat called 'schmutzedecke' in the bed. It was believed that chemical pretreatment of the raw water

would interfere with the formation of 'schmutzedecke' hampering filtration, but Agarwal (1973) showed that higher rates of filtration (upto 1.00 $m^3/m^2/hr.$) are possible with chemical pretreatment of the raw water. Under the low rates of filtration presently adopted, slow sand filters require large area and can be employed economically only in rural areas where land cost is low.

2.1.2 Rapid sand filters

As the name implies, these filters operate at much faster rates (4.4 to 5.9 $m^3/m^2/hr.$) than the slow sand filters and hence require considerably lesser area. The distinguishing features of a rapid sand filter are the coarser media (0.45 mm and higher), penetration and removal of suspended and colloidal matter throughout the depth of the bed and mechanical backwashing systems. Due to the higher rates of accumulation of impurities, frequent backwashing is required in rapid sand filters. Back-washing is done by upward flow of previously filtered water. The settling of media grains after backwashing results in stratification of the bed with the finest or lightest material at the top and the coarsest or heaviest material at the bottom. This stratification hinders indepth filtration and in effect removal will be only in the first few inches of the media.

2.1.3 Pressure filters

In pressure filters the media and underdrains will be contained in a steel tank. The filter operates at a pressure of about 17 kg/cm^2 and the filtration rates range from 5 to 9.7 $m^3/m^2/hr$. Pressure filters are normally used in small treatment units like industries and swimming pools.

2.2 Theory of filtration

Action of a rapid sand filter is a complex physicochemical process which is influenced by the characteristics of the suspension and the filter media and the rate of filtration. The removal efficiency of a clean filter depends on physical and physicochemical characteristics of suspended particles and filter media like size, density and surface characteristics, hydrodynamic characteristics like filtration velocity and also on the depth and porosity of the filter bed. The head loss at the start of the filtration depends upon media size, filtration rate and bed porosity. In the succeeding sections the existing literature about the removal mechanisms and theories on head loss development is briefly discussed.

O'Melia and Stumm (1967) proposed that the process of filtration involves two steps, viz., transport of the suspended particles to the media and attachment of the transported particles to the media. Particle transport can be

considered to be a physicochemical and physical hydraulic process which is affected by such physical parameters as size of filter medium, filtration rate, fluid temperature and density and size of suspended particles. Particle attachment is a chemical process and is influenced by both physical and chemical parameters.

In the early years of the development of the theory of filtration, emphasis was given to the hydraulics of the process and mechanism of removal was given little considerations. Carman., Kozeney and Rose developed empirical relationships for the head loss developed in a filter. These engineers visualised filtration to be mere flow through porous media without giving any thrust on removal efficiency. Later Iwasaki postulated the semirational approach to the mechanism of filtration considering the removal of particles in a filter bed. Hall, Ives, Agrawal, Yao and others postulated theories for the different mechanisms of removal in a filter bed which form the basis of further discussion.

Iwasaki (1937) developed a first order equation for the removal of suspended solids in filtration

$$-\frac{\partial C}{\partial L} = \lambda C \tag{2.1}$$

where C is the concentration of particles at any time, L is the depth of media and λ is the filter coefficient. λ varies with time and depth. Iwasaki's equation was based on

his observations and was purely empirical. The value of λ can be calculated according to Agrawal (1966) by determing the number of grains in unit depth of filter media and removal efficiency of each grain from the following relationship

$$\lambda = k \frac{1.5\,(1-f)\eta}{d_m} \qquad (2.2)$$

where f is the porosity of the bed,

d_m is the diameter of media grain

η is removal efficiency of a single collector and

k is a factor describing interference effect by neighbouring grains in a packed bed.

Agrawal's equation was based on the theory of filtration of aerosol particles where it is assumed that the total removal is contributed by individual fibres (or in the case of granular filters by individual grains) and an individual grain totally removes all particles from a certain percentage of its projected area confronting the flow.

As filtration is basically a physicochemical process, parameters like size, shape and nature of media grains and suspended particles, flow characteristic like rate of filtration, influent water characteristics like temperature, viscosity, alkalinity and pH all influence the efficiency of the grains and hence λ. As filtration proceeds, the

porosity of the bed changes due to deposition which inturn change media properties and λ goes on changing during filtration. λ_o - the initial filter coefficient indicates the efficiency of a clean filter bed where media characteristics can be determined somewhat more accurately. Therefore the particle removal mechanisms developed for explaining filtration phenomenon are based on relation between various parameters and the λ_o value.

Yao (1971) introduced a coefficient in the first order equation of filtration and expressed it as follows:

$$-\frac{\partial C}{\partial L} = \frac{1.5\,(1-f)}{d_m}\,\eta\,\alpha\,C \tag{2.3}$$

and

$$\lambda = \frac{1.5\,(1-f)}{d_m}\,\eta\,\alpha \tag{2.4}$$

where

α = collision efficiency factor = $\dfrac{\text{number of contacts which succeed in producing adhesion}}{\text{number of collision between suspended particle and media grain.}}$

As filtration proceeds, suspended solids get deposited in the filter bed changing the media characteristics like grain size, porosity, surface charge and pore size which affect the filtration efficiency. Change in porosity is given by the specific deposit which is expressed as the fraction of the pore volume occupied by deposit. As the specific deposit

increases, the surface characteristics of the media also change thus changing the filter coefficient. Ives (1960) proposed the following equation for λ by taking into account the shearing of deposited flocs due to increase in interstitial velocity.

$$\lambda = \lambda_o + C'\sigma - \frac{\varphi\sigma^2}{-\sigma} \tag{2.5}$$

where λ_o is initial filter coefficient

σ is the specific deposit and

C' and φ are the system constants.

Ives and Sholji (1965) related λ_o, C' and φ with three main physical parameters of filtration and expressed them as follows:

$$\lambda_o = \frac{K_1}{d_m V \mu^2}$$

$$C' = \frac{K_2}{d_m V \mu^{1.2}}$$

$$\varphi = \frac{K_3}{d_m V \mu^2}$$

where V is the superficial velocity of filtration,

μ is the viscosity of the fluid and

K_1, K_2 and K_3 are constants depending on media and suspension characteristics and require pilot plant studies for their determination.

Ives (1967) developed a mathematical model assuming that the filter coefficient λ is a function of specific surface and interstitial velocity

$$\lambda = \lambda_o \left(1 + \frac{b\sigma}{f}\right)^y \left(1 - \frac{\sigma}{f}\right)^z \left(1 - \frac{\sigma}{\sigma_u}\right)^x \qquad (2.6)$$

where b is a geometric constant relating to the packing of the grains,

σ_u is the ultimate specific deposit and

y, z, and x are empirical exponents.

2.3 Removal mechanisms

O'Melia and Stumm (1967) proposed that the process of filtration involves a transport step where by particles are transported to the collector and an attachment step in which the transported particles adhere to the media grain or particles already deposited.

2.3.1 Mechanical straining

Fair and Geyer (1954) and Hall (1957) suggested that mechanical straining plays a significant role in the removal of suspended solids. They considered pores in every layer of the media as sieve openings. Hall assumed that when flow takes place normal to these areas, pore openings which are smaller than the particles will trap the suspended solids thus stripping the water of such particles. Hence straining is a function of

particle to grain size ratio. In a filter with sand of effective size 0.3 to 0.6 mm, the pore effective size is of the order of 100 microns whereas particles or flocs to be retained seldom exceed 30-50 microns (Agrawal, 1966), Hall (1957) pointed out that eventhough the average pore size is larger than the particles, sharp corners exist in the filter which can trap smaller particles. Based on his analysis, Agrawal (1966) showed that clean bed filter coefficient λ_o can be expressed as follows

$$(\lambda_o)_{st} = 3.5\, d_p^{3/2}\, d_m^{-5/2} \tag{2.7}$$

where $(\lambda_o)_{st}$ is the filter coefficient due to straining and d_p and d_m are the diameters of particle and media grain respectively. Herzig _et. al_. (1970) showed that the particle to grain size ratio should be atleast 0.05 for straining to be important. Agrawal showed that major flow in the filter is diverted from the corner spaces where openings are smaller and hence mechanical straining cannot be the sole mechanism responsible for the removal of particles.

2.3.2 Gravity settling

Ranz and Wong (1952) applied settling theory to find out efficiency of removal of aerosol from a horizontally flowing gas stream. Extending this to water filtration, the efficiency of a single grain is given by the ratio of the

settling velocity of the particle to the velocity of flow of water and the filter coefficient (λ_o) is given by

$$(\lambda_o)_g = 1.5\,(1-f)\,\frac{g d_p^{\,2}\,(\rho_p - \rho_1)}{18\,\mu\,d_m\,V_o} \tag{2.8}$$

where $(\lambda_o)_g$ is the clean bed filter coefficient due to gravity settling,

g is acceleration due to gravity

ρ_p and ρ_1 are the mass density of particle and media grains respectively and

v_o is the superficial velocity of flow

Agrawal (1966) questioned the applicability of the above equation as it is derived for horizontal flow and in water filtration the fluid itself is moving in a vertical direction with a velocity much larger than the settling velocity of the particles. However, Ives (1971) reported nonvertical flow of the fluid through the bed capillaries and low velocity zones which aid in settling of the particles.

2.3.3 Interception

Removal by interception is achieved when actual contact of the particles and grain takes place as the turbid water flows in streamlines past the media grain.

Agrawal (1966) expressed the efficiency of single grain due to interception as

$$\eta = KR^2 \qquad (2.9)$$

where R is the interception parameter $= \frac{d_p}{d_m}$

2.3.4 Impaction

Often termed as inertial impingement, this is due to the fact that owing to their inertia suspended particles do not adhere to the bending fluid streamlines when they approach an obstacle, but tend to continue in the original direction of flow thus having a greater chance of collision than would be predicted if they were to follow the streamlines. Agrawal (1966) expressed the inertial parameter as follows:

$$I = \frac{\rho_P d_p^2 V_o}{9 \mu d_m} \qquad (2.10)$$

Agrawal showed that in water filtration due to low velocity of flow and high viscosity I is very low and hence removal due to impaction is negligible.

2.3.5 Brownian diffusion

Particles in a suspension are at random motion with varying velocities, the mean value being proportional to KT where K is Boltzman's constant and T is absolute temperature. The number of particles moving in one direction is equal to the number of particles moving in the opposite

direction and hence the concentration remains the same. But if particles colloiding with the container surface or collector surface were effectively adsorbed on the surface, a concentration gradient would result and due to this more particles will move to the surface. Thus a net flow of particles towards the collector surface results. Levich (1962) developed an equation for determining the single collector efficiency (η_D) with Peclet Number (P_e) as dimensionless parameter representing combined convective diffusion

$$\eta_D = 4.04 \, P_e^{-2/3} \tag{2.11}$$

where P_e is the ratio of transport by convective forces to transport by diffusion $= \frac{V_o L}{D_B}$

D_B is coefficient of Brownian motion $= \frac{KT}{3\pi\mu d_p}$ where K is Boltzman's constant, T is absolute temperature, μ is viscosity and d_p is diameter of particle.

Hence $$\eta_D = \frac{4.04}{(V_o L)^{2/3}} \left(\frac{KT}{3\pi\mu d_p} \right)^{2/3} \tag{2.12}$$

Putting $L = d_m$

$$\eta_{\text{diffusion}} = \frac{1.5\,(1-f)}{d_m} \; \frac{(KT)^{2/3}}{(\mu d_p d_m V_o)^{2/3}} \tag{2.13}$$

Removal by diffusion is significant only in the case of particles with size less than 1 µM. Virus particles are most effectively transported by diffusion mechanism to the collector surface.

2.3.6 Attachment mechanism

Ives (1971) indicated that double layer interaction, molecular forces and mutual adsorption are main forces responsible for attachment. O'Melia and Stumm (1967) and other researchers proposed the double layer model and bridging model for the attachment of particles to the media grains. Agrawal (1966) showed that these mechanisms alone could not play any significant role in removal and proposed the electrokinetic phenomena.

2.3.7 Double layer interaction

O'Melia and Stumm (1967) suggested that the net interaction between suspended solids and filter surface can be described by a combination of vander Waal's force with Coulombic repulsion or attraction of the two double layers. Agrawal (1966) and Ives (1971) concluded that under normal conditions of water filtration double layer interaction is not significant due to extremely small range of action.

2.3.8 Molecular forces

Molecular forces were first coneeived by vander Waal and is the force of attraction between two molecules when they are very close to each other. London gave an equation for this force usually known as London vander Waal's force

$$\mu = \frac{K}{R^6} \tag{2.14}$$

where u is the force of attraction,

R is the minimum distance of separation between the molecules and K is London vander Waal's constant and is dependent on the properties of the molecules a_1 and a_2 which are attracted to each other.

The London vander Waal's theory was first extended to particles in vacuum and then to particles in fluid Molecular forces are supposed to be responsible for the clumping of colloids on the collector surface. Mackrle and Mackrle (1961) proposed the concept of adhesion space and assumed that particles entering this layer will be removed. Agrawal (1966) reports that molecular attraction is not likely to play any significant role in the removal of particles.

2.3.9 <u>Electrokinetic phenomena</u>

Agrawal (1966) showed that electrokinetic phenomena play significant role in the removal of suspended particles in the media. The suspended particles are surrounded by an electrical double layer and as the water flows past the media the double layer gets continuously sheared off setting up a streaming potential. Agrawal observed that in negatively charged media the streaming potential is such as to make the bottom layers slightly more positive and vice versa in positively charged media. Hence negatively charged particles are attracted to the bottom in a sand media and are carried off

through the effluent whereas positively charged particles are repelled and removed.

The electrokinetic force is proportional to the Zeta Potential (Z.P.) of the media and charge of the particle. The Z.P. of the media in turn depends on the streaming potential. Agrawal developed the following equation for the removal of particles due to electrokinetic phenomena

$$\lambda_o = \frac{7(1-f)E}{d_m} \qquad (2.15)$$

where

E is the electrokinetic force = $\left(\frac{K_2 \zeta_p^2 C\, d_m}{\mu V_o} - \frac{K_1 \zeta_m \zeta_p d_p}{\mu V_o}\right)$

where ζ_p and ζ_m = Z.P. of particle and media respectively

d_p and d_m = diameter of particle and media respectively

C = concentration of particles by volume fraction and

K_1 and K_2 are constants varying probably with only temperature and ionic concentration of water.

Studies conducted by Agrawal showed strong dependence of the overall removal on suspension and media surface charges and he suggested that there is a possibility of improving filtration by using suitable media.

2.3.10 Role of retained particles

O'Melia and Waris Ali (1978) formulated a model for the removal efficiency during filtration by packed beds, based on the theory that some retained particles can act as filter media and thus improve filtration efficiency. The particle removed initially provides an additional contact site for further deposition. Thus chains or dendrites of particles are formed improving further removal of particles. They proposed that the contact efficiency η_c comprises of the contact efficiency of the filter grain and its associated retained particle. They expressed η_c as

$$\eta_c = \eta + N\eta_p \left(\frac{d_p}{d_c}\right)^2 \tag{2.16}$$

where η_c = combined contact efficiency

η = contact efficiency of filter grain

$$= \frac{\text{rate at which particles strike the filter grain}}{\text{Rate at which particles flow towards the grain}}$$

N = number of particles retained on the grain which act as collectors

η_p = contact efficiency of a retained particle =

$$\frac{\text{rate at which particles strike a retained particle acting as collectors}}{\text{rate at which particles flow towards the retained particle acting as collector.}}$$

d_p = diameter of suspended particle

d_c = diameter of collector

Expressing the particle to grain and particle to particle attachment coefficients as α and α_p respectively the removal efficiency is given by

$$\eta_r = \alpha \eta + N \alpha_p \eta_p \left(\frac{d_p}{d_c} \right)^2 \qquad (2.17)$$

O'Melia and Ali (1978) developed the following equation for estimating the change in number of particles acting as collector with time

$$\frac{\partial N}{\partial t} = \eta \alpha \beta n v_o d_c^2 \left(\frac{\pi}{4} \right) \qquad (2.18)$$

n is the initial undisturbed particle concentration,

v_o is the approach velocity and

β is the fraction of particles retaine directly on the filter grain which can act as additional collectors.

In developing the above equation they neglected the change in surface coverage of filter media grains and that of retained particles acting as collectors that must occur with time and with depth.

Tare (1979) took the above factors into consideration and proposed the following equation for a filter layer of thickness ΔL

$$\frac{\partial N}{\partial t} + V_o \frac{\partial N}{\partial L} = [C_1 + (C_2 - C_3)N - C_4 N^2]\, n \qquad (2.19)$$

where $C_1 = \eta \alpha v_o \frac{\pi}{4} d_c^2$; $C_2 = \eta_p \alpha_p v_o \frac{\pi}{4} d_p^2$,

$C_3 = \eta_p \alpha_p v_o \frac{\pi}{4} d_p^2 \beta_c$ and

$C_4 = \eta_p \alpha_p v_o \frac{\pi}{4} d_p^2 \beta_p$,

2.4 Head loss theory in filtration

Carman (1937) expressed the general equation of flow through the filter media as

$$V_e = g \frac{R^2}{K_o} \frac{1}{\nu} \frac{\Delta H}{L} \qquad (2.20)$$

V_e = actual average velocity in a porous media

K_o = Karman's shape factor

R = hydraulic radius = $\dfrac{\text{Volume of fluid in the pipe}}{\text{Surface area in contact with the pipe.}}$

$= \dfrac{f}{(1-f)S_o}$ for a porous media where S_o is the specific surface area

ν = kinematic viscosity of the fluid

$\frac{\Delta H}{L}$ = hydraulic gradient

Since the flowing fluid has to follow a sinuous path through the porous media it has to cover a greater distance than that tiven by the external dimensions of the media. Also the actual average effective length of the flowing fluid is greater than the length of the media and hence there will be an increase

in the average rate of flow V_e by a ratio $\frac{L_e}{L}$ and a decrease in $\frac{\Delta H}{L}$ by a similar ratio. Thus Carman substituted $\frac{V}{P}\ \frac{L_e}{L}$ for V_e, replaced R by $\frac{f}{(1-f)S_o}$, reduced $\frac{\Delta H}{L}$ by $\frac{L}{L_e}$ and obtained the Kozeney - Carman equation from equation (2.20)

$$\frac{\Delta H}{L} = \frac{\nu V S_o^2}{g} K_o \left(\frac{L_e}{L}\right)^2 \frac{(1-f)^2}{f^3} \qquad (2.21)$$

In the above equation the parameter $K_o\ (\frac{L_e}{L})^2$ is known as Carman-Kozeney constant K. It was shown experimentally by Carman that over a wide range of geometrical shapes K_o varies between 1.52 and 3 with an average range of 2 to 2.5. For unconsolidated porous media Carman suggested a value of 2.5 for K_o and 2.0 for $(\frac{L_e}{L})^2$, thus making K to 5.

Carman-Kozeney's equation is applicable only for clean filter beds. During filtration suspended particles get deposited in the filter bed which is termed as specific deposit. Due to the specific deposit, the porosity of the bed is reduced and hence the head loss increases. Some attempts have been made to develop equations for head loss during filtration. Mackrle (1965) proposed a mathematical model for the change in surface area per unit volume of matrix with respect to three factors x, y and p. Mohanka (1969) incorporated Mackrle's model in Carman-Kozeney's equation and obtained equation for head loss in clogged bed as follows:

$$\frac{H}{H_0} = \left(1 + p\frac{\sigma}{f}\right)^2 \left(1 - \frac{\sigma}{f}\right)^{-1} \qquad (2.22)$$

where

$$P = \frac{29}{S^{0.65}} = 9.05 \left(\frac{\varphi\, d_m}{1-f}\right)^{0.65}$$

φ = sphericity of filter grain

Mohanka assumed Kozeney-Carman constant remained unchanged during filtration and took into account the change in surface area and porosity of the bed. Deb (1969) developed an equation in deriving which he assumed that during filtration deposition takes place unformly on the surface of the grain.

$$\frac{H}{H_o} = \left[1 + G(1-10^{-K\sigma}) \left(\frac{f}{f-\sigma} \right)^3 \right] \qquad (2.23)$$

where H is head loss during filtration,

H_o is the head loss in a clean filter bed,

f is the porosity

σ is the specific deposit and

G and K are empirical constants with values 3.2 and 13.3 respectively. Sakthivadivel (1972) discussed the models given by Camp, Deb, Mohanka and others and concluded that the equations predict the head loss during filtration within a reasonable degree of accuracy and the values of head loss given by the different equations do not vary much for the laminar flow conditions.

O'Melia and Waris Ali (1978) developed the following equation for head loss during filtration by considering the change in interfacial surface area as dendrites develop

$$\frac{h_f}{L} = \frac{36}{d_c^2} K \mu \frac{v_o}{g} \frac{(1-f)^2}{f^3} \left[\frac{\left(1+\beta' \frac{N_p}{N_c} \left(\frac{d_p}{d_c}\right)^2\right)}{\left(1 + \frac{N_p}{N_c} \left(\frac{d_p}{d_c}\right)^3\right)} \right]^2 \qquad (2.24)$$

h_f is the head loss during filtration,

L is the depth, of layer under consideration

N_c and N_p are the number of filter grains and retained particles in the filter bed and

β' is an empirical coefficient that represents the fraction of retained particles that are exposed to the flowing fluid and contribute to additional surface area.

In the above equation the bed is divided into several layers as deposition is nonuniform with depth and $\frac{h_f}{L}$ is to be calculated for each layer.

2.5 Filterability Number - a new concept of filterability

Ives (1978) proposed the concept of Filterability Number relating the filterability of a suspension to filter material taking into account clarification, clogging and flow rate. The Filterability number (F·N) is given by

$$F.\ N. = \frac{HC}{VC_o t} \tag{2.25}$$

where H is the head loss

C is average filtrate quality

C_o is the inlet suspension quality

V is the approach velocity and

t is the time of the filter run

For good filterability, the head loss and filtrate concentration should be low. Also the approach velocity (rate of filtration) and the duration of filtration should be long.

No particular significance can be attached to the actual numerical value of F.N. but relative values of F.N. indicate relative filterabilities and hence can be applied in comparing different media suspension combinations. Further, this concept can be used to evaluate the optimal conditions for efficient filtration like optimum flow rate, media size and pre-treatment before conducting costly and cumbersome pilot plant studies. However, as indicated filterability number can serve only as a simple tool to screen out initial experimentation so that costly pilot column studies can be conducted only with prospective parameters.

2.6 Development of new media for filtration

Various materials have been tried in the past as filter media with the objective of improving the rate of filtration and reducing the cost of operation. Kardile (1972) developed a coarse media for dual media filter from crushed coconut shell. Anthracite has been used as a common filter media. Ranade (1976) used bituminous coal in the top layer of a dual media filter. Frankel (1974) conducted laboratory studies using locally available materials like peat, gravel, charcoal, coconut husk and rice husk as filter media. The media were tested for high rates of filtration with high raw water turbidity (100-400 JTU) and low rates of filtration with low influent turbidity to evaluate the effectiveness of the same as a roughing filter and polishing filter respectively. It was observed that chopped coconut husks served as a good media for roughing filter whereas burned rice husk was the best suited for polishing filters. Mörgeli and Ives (1979) report that pumice and hydroanthracite have been used as filter media in water treatment. They conducted laboratory and pilot plant studies with pumice and expanded slate in dual media filters for effluent filtration and found that development of head loss in expanded slate for nearly the same fraction removal $\frac{C}{C_o}$ was higher than that in pumice and hence they inferred that the adsorption capacity of expanded slate is less than that of pumice.

2.7 Utilization of coconut shell as a filter media

Kardile (1978) conducted extensive laboratory and pilot plant studies to explore the utility of materials like fused brick, fused concrete and coconut shell as a media in filters. The results obtained in the case of crushed coconut shell were encouraging as they were comparable to or better than those for bituminous coal or sand. Kardile reports that eventhough the cost of crushed coconut of size 1 to 2 mm is about 3 times that of fine sand, it may be cheaper than other materials used in dual **media** filters as coarse media. Where coconut is available in plenty and shells are wasted as fuel, the cost of the media may be less. The state of Kerala produces 90 percent of the total yield of coconut in India and shells are available at nominal cost. Studies condu- **cted at** CSIR **Lab.** Trivandrum show that shells can be used in the commercial and industrial field as a raw material for various purposes. Analysis of shell charcoal conducted at CSIR **Lab.** show a moisture content of 10 percent, ash of 2 percent and volatile acid of 15.0 to 30 percent. Pilot plant studies on filtration conducted by Kardile (1978) showed that the head loss developed in a rapid sand filter is about 2 to 3 times more than that in a filter bed with crushed coconut shell media. Hence coconut shell, where it is cheaply available may be used as a media in filters. The present investigation was aimed at determining the effectiveness of such a media in filtering water under

different pretreatment conditions.

2.8 Direct filtration for treatment of water

Direct filtration is defined as a series of operation involving coagulation, flocculation and filtration without sedimentation. Hutcheson (1974) and Sweeny (1974) report that the process can be an effective and economical alternative to conventional water clarification. The elimination of sedimentation or large conventional flocculating tanks can significantly reduce the cost. Direct filtration is most often applied when the raw water turbidity is relatively low. Tate and Trussel (1979) report that direct filtration is effective in the removal of color from raw water. However, Letterman *et al.* (1979) doubt the applicability of single media filters in direct filtration. They suggest dual media filters for direct filtration as the flocs will be trapped in the larger grained upper layer of the filter giving rise to lower head loss per unit of deposit.

Letterman *et al.*(1979) conducted direct filtration studies on dual media filters with a cationic polyelectrolyte as the sole coagulant in treating water with an initial turbidity of 32 FTu. They report, [illegible] turbidity reduced during the ripening period to 0.05 FTU and remained at this level till the end of the run. Their experiments showed that direct filtration could be used effectively for treating water with moderately high

turbidities and effective operation could be achieved by pretreatment control.

Pilot plant tests and plant scale operations were conducted by Monscvitz et.al.(1978) with lake water of low turbidity containing plankton. The pilot tests revealed that filtration with conventional pretreatment was superior to direct filtration, but the improvement in performance did not warrant the additional expense of including a sedimentation tank. They also observed that the amount of coagulant required with sedimentation was 25 to 40 percent greater than that for treatment without sedimentation. Laboratory studies on direct filtration by Treweek (1979) on a simple sand filter bed indicate that flocculation for 20-30 minutes produce heavy voluminous flocs which are not conducive to optimum filtration. On the other hand flocculation for a shorter period at higher velocity gradients produce flocs which are effectively removed in the sand filter.

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Media Crushed coconut shell and Ganges sand were used as the media for filtration. Coconut shell was crushed in a roller mill and sieved through I.S. sieves to get grains of required sizes. Media of geometric mean size 0.55 mm (passing through 0.6 mm sieve and retained on 0.50 mm sieve) and 0.65 mm (passing through 0.7 mm sieve and retained on 0.6 mm sieve) were used for experimental studies. The grains were thorughly washed and dried before use.

Sand of the same size as of crushed coconut shell was used for comparison of the performance of the two different media.

3.1.2 Clay Kaolinite clay supplied by Cosmos Industries Varanasi was used to prepare the stock suspension for raw water preparation.

3.1.3 Protein Albumin supplied by Sigma Chemicals, U.S.A. was used for making protein suspension for the adsorption studies.

3.2 Methods

The experiments were conducted in two phases. In phase (1) the filterability number (F.N.) was determined for sand and crushed coconut shell of two different sizes for different flow rates of raw and partially pretreated water.

In phase (2) column studies were conducted at two different flow rates with raw, pretreated and partially pretreated water.

3.2.1 Preparation of clay suspension

Stock suspension of clay was prepared as suggested by Olphen (1963). The clay was suspended in distilled water and stirred rigorously for about 10-15 minutes. The clay concentration was kept as high as can be stirred by the mechanical stirrer. The suspension was then diluted with distilled water to enable gravity settling of the particles. Due to the presence to electrolytes in the clay sample, flocculation and hence rapid settling of the minerals take place. The supernatant was siphoned off and the clay was again dispersed in distilled water by stirring. This procedure was repeated till the concentration of electrolytes was lowered below that required to effect the flocculation and the clay fraction remained in suspension due to peptization. This is the process of stabilization of clay suspension by the reversal of positive edge charge into a negative one. Partices settling rapidly at this stage were discarded off and the suspension was used as the stock suspension for preparing the turbid water for filtration. Required quantities of the stock suspension were added to laboratory tap water and mixed thoroughly for 15 min. to get a turbidity of 30-36 NTu.

3.2.2 Determination of Coagulant dose

Commercial alum (potassium aluminum sulfate) was used as the coagulant. Alum dose required for optimum settling after flocculation was determined by the jar test method using a six gang laboratory flocculator with variable speed (Phipphs and Bird). This optimum dose was added to water in filtration experiments with complete pretreatment, According to Monscvitz et al. (1978) the alum dose required for filtration after sedimentation is 25 percent to 40 percent more than that is required for direct filtration(without sedimentation). Hence, in the present studies optimum dose of alum required for direct filtration was also determined by conducting jar tests by varying the alum dose.

As the optimum dose obtained from jar tests may not necessarily represent that required for large volumes of water, it was decided to conduct coagulation experiments in a 60 litre capacity container with 45 litre of water. A paddle flocculator was used in the tests.
A 'Remi stirrer' with an autotransformer was used to vary the speed of the paddle flocculator. The minimum speed attainable was found to be 30-32 rpm which correspondes to a velocity gradient (G) range of 47-50 sec^{-1}. The speed of the flocculator was adjusted to 30-32 rpm and the alum dose required for maximum clarification was determined. This alum dose was used in column studies with complete pretreatment

(coagulation, flocculation and sedimentation) and 75 percent of this was used for coagulation in column studies of direct filtration experiments.

3.2.3 Determination of media characteristics

(a) Specific gravity Specific gravity of sand and crushed coconut shell was determined by the standard pycnometer method. Specific gravity was obtained from the relation specific gravity $= \frac{w_2-w_1}{(w_4-w_1)-(w_3-w_2)}$ where w_1 is the wt. of dry pycnometer,

w_2 wt. of pycnometer and media

w_3 wt of pycnometer and media and water upto the brim

w_4 wt. of pycnometer and water.

(b) Porosity Porosity determination of the media was done as per specifications given in tentative standard (1949)

Porosity is given by percentage porosity

$= \frac{V - \frac{w}{sp:gr}}{V}$ x 100 where V is the volume of the media observed in the cylinder and w is the weight of the media.

(c) Sphericity Sphericity of the media was determined by conducting settling tests of the media. The media grains were allowed to fall through a column of water of depth

50 cms and the settling velocities were calculated. The sphericity of the media was calculated from the relation given by Fair et.al. (1968)

$$\text{Sphericity } \psi = \sqrt{\frac{V_s}{V_o}} = \sqrt{\frac{V_s}{\frac{gd^2}{18\nu}(S_s-1)}} \quad \text{where}$$

v_s is the actual velocity of the media and

v_o is the Stoke's settling velocity of equivalent volume sphere.

(d) <u>100 hr backwash test or attrition test</u>

Sand and crushed coconut shell of GM size .055 mm were taken in two glass columns of 25 mm diameter and backwashed for 100 hr. The rate of backwashing was adjusted to give an expansion of 45-50 percent. The percentage loss in weight of media was determined after 100 hr.

3.2.4 Phase 1 studies - determination of F.N.

The phase 1 studies were carried out to find out the optimum combination of media and extent of pretreatment. The experiments were grouped into three different sets, the first set being intended to deduce from the experiments on filterability number whether direct filtration (partial pretreatment) and only filtration (no pretreatment) were feasible. The second set of experiments consisted of direct filtration where the velocity

gradient (G) for flocculation was varied and the G value which produced a flocculated suspension for optimum direct filtration was determined. In the third set direct filtration was carried out for different flow rates at a G value which produced optimum direct filtration. In all the experiments sand and crushed coconut shell of geometric mean size 0.55 mm and 0.65 mm were used.

Experimental set up The experimental set up used for the determination of F.N. is shown in Fig.3.1. Glass columns of 130 mm length and 40 mm diameter were used for the experiments. Two ports of dia. 0.5 mm each were provided at a distance of 100 mm from each other to connect manometers. A glass plate with pores and a steel wire mesh fixed on to it served as the support to the media. The column was connected to 1 litre separating funnels through rubber tubes. An initial head of 60 cm was available for filtration. An air release port was provided at the top of the column.

Sand and crushed coconut shell of G.M. size 0.55 mm and 0.65 mm were used as the media. The columns were filled with the media to a depth of 45 mm and backwashed to expel air. Filtration was carried out simultaneously in the two columns to compare the performance of the two media.

Raw water of initial turbidity 30-36 NTu was used without pretreatment and with partial pretreatment.

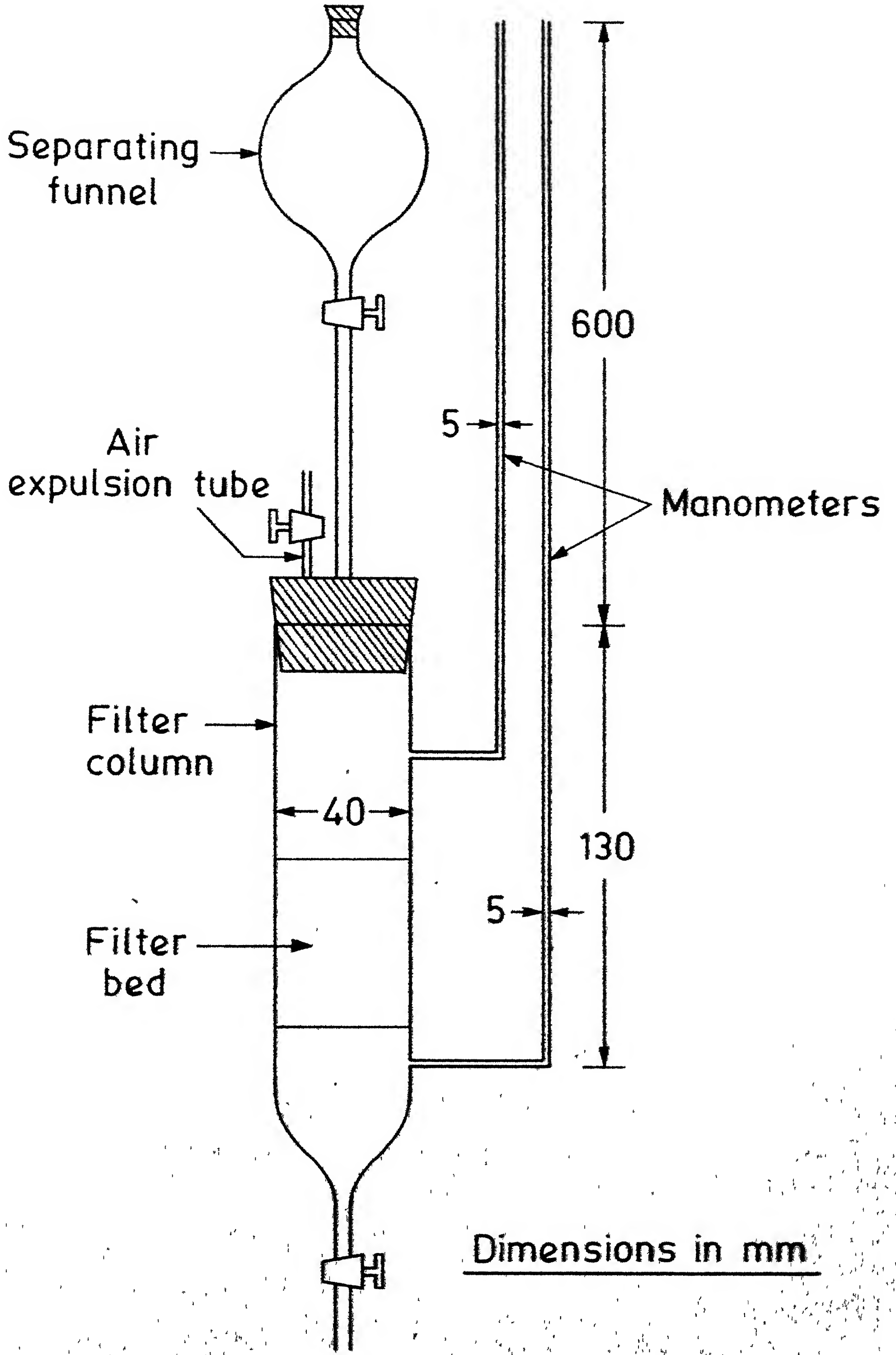


Fig. 3.1- Experimental setup for determination of F.N.

Filtration was carried out at a standard flow rate of $5\ m^3/m^2/hr$ and the average effluent turbidity and the head loss at the end of filter run were measured. The time required for filtering 1 litre of the suspension was also noted. A Hach turbidimeter model 2100 A was used to measure the turbidities. Standard turbidity suspensions were prepared as per Standard Methods (1975) for calibrating the turbidimeter. The F.N. was calculated from the relation $F.N. = \frac{CH}{C_o vt}$.

Direct filtration was carried out with different doses of alum with a view to determining the optimum alum dose for direct filtration. In all the experiments a G value of $40\ sec^{-1}$ was provided for flocculating the raw suspension.

The second set of experiments consisted of direct filtration with flocculation at different G values and at a flocculation period of 10 min. The rate of flow was kept $5\ m^3/m^2/hr$. The optimum GT value obtained from this set of experiments was used in the third set to carry out filtration at different flow rates.

3.2.5 Phase 2 - column studies

Experimental set up The experimental set up used for column studies is shown in Fig. 3.2. Glass columns of length 120 cm and diameter 28 mm were used for this purpose. Ports were provided on diametrically opposite sides of the column at depths of 13.5 cm, 24 cm, 33.5 cm, 49 cm and 65 cm from the top for

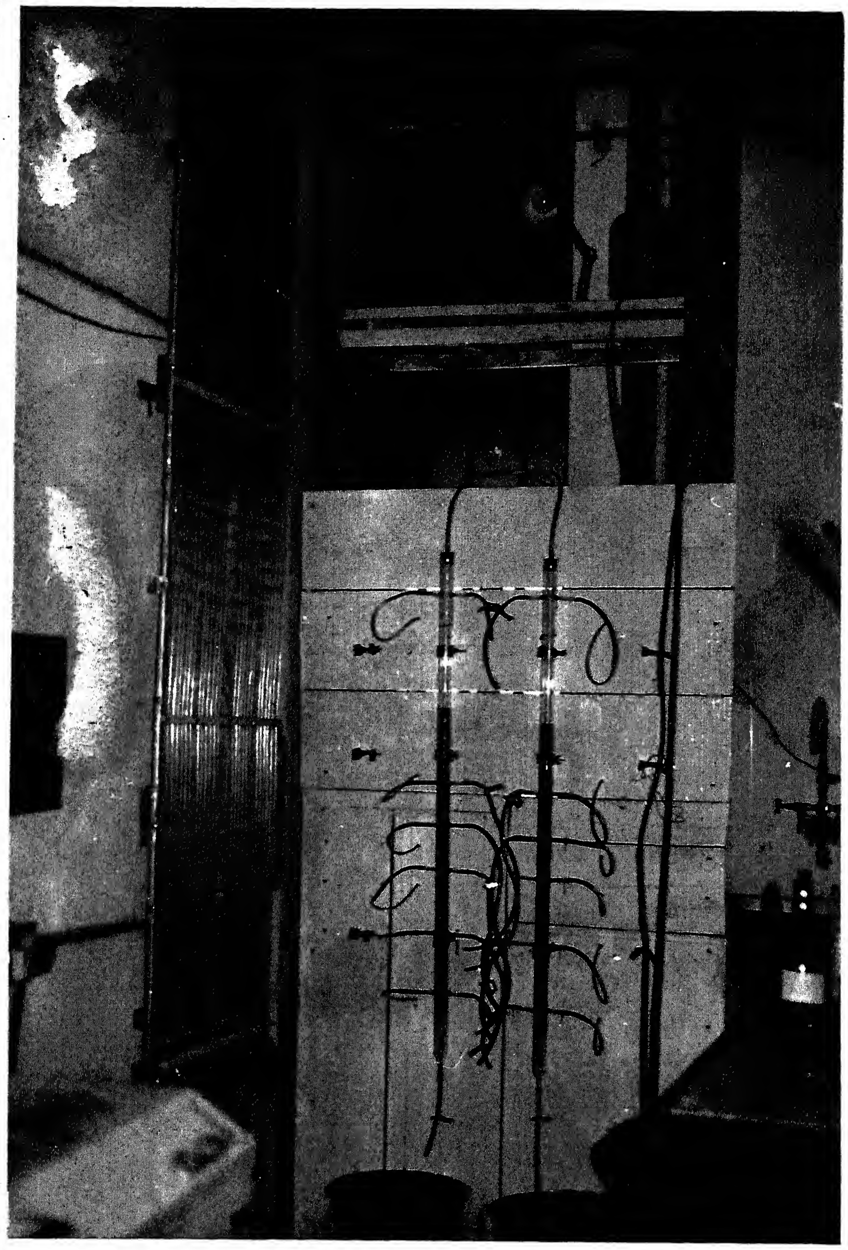


FIG. 3.2 EXPERIMENTAL SETUP FOR COLUMN STUDIES

connecting manometers and for the withdrawal of samples. These ports were covered with brass wire mesh to prevent the loss of material.

The suspension to be filtered was continuously pumped into a reservoir kept above the column so as to provide a constant head of 110 cm above the media. The columns were connected through rubber tubes to the reservoir. Flow rates were adjusted by pinch cocks.

45 l of raw water with an initial turbidity of 30-33 NTu was prepared each time in a 60 litre plastic drum by adding requisite quantity of the stock suspension to tap water and stirring thoroughly by means of the paddle stirrer for 15 minutes. The suspension thus prepared was transferred into a storage container from which it was pumped into the reservoir. Flocculated suspension was prepared in the same manner by adding 30 mg/l of alum, flash mixing for one minute at maximum speed available with the stirrer and then flocculating at 30-34 rpm for 20 min. The flocculated water was allowed to settle for 20 min. and the clear water was siphoned off for pumping.

Coagulation prior to direct filtration was done with 22 mg/l of alum and flocculation was performed for 10 min. at a speed of 48-50 rpm. The flocculated suspension was transferred immediately to the second drum for pumping.

Column studies were conducted with raw water, settled water and partially pretreated water. Flow rates of 5 $m^3/m^2/hr$ and 7.5 $m^3/m^2/hr$ were tried to study the performance of the media for three types of pretreatments. The duration of filter runs varied from 8 to 22hr depending on the headloss building across the media. Head loss and turbidity were measured in each case at different depths of media at different intervals of time.

3.2.6 Adsorption studies

Batch tests on adsorption were carried out to determine whether adsorption is an operative mechanisms in the removal of particles in the bed. Tests were conducted with clay and albumin suspension. 100 ml of suspension and 10 g of media were taken in each bottle and the bottles were kept stirred in a laboratory stirrer for 1½ to 2 hours. Samples were withdrawn at different intervals of time and turbidity measurement and protein estimation were done on clay and protein suspensions respectively. The protein estimation was done by Biuret assay method (Practical Biochemistry, 1971) based on the principle that alkaline copper sulphate reacts with compounds containing two or more peptide bonds to give a violet colored complex. The depth of the color obtained is a measure of the number of peptide bonds present in the protein.

4. RESULTS AND DISCUSSION

The present investigation is directed to evaluate the potential of crushed coconut shell (C.C.S.) as a filter media for different pretreatments. The performance of shell filter was always compared with conventional sand filter to rate whether the new media is superior, equal or inferior to standard sand media filter. In the following sections the performance of crushed coconut shell as filter media is described.

4.1 Characteristics of the media

A number of tests are to be carried out to check the suitability of a media when it is proposed for filtration. A comparative study of the characteristics of sand and crushed coconut shell are given in Table 4.1.

Table 4.1 Characteristics of Sand and C.C.S.

Characteristics	Sand	Shell
Geometric mean size	0.55 mm	0.55 mm
	0.65 mm	0.65 mm
Porosity (G.M. size (0.65 mm)	0.42	0.61
Specific gravity	2.65	1.41
Percentage loss after 100 hrs back wash	0.5	0.5
Sphericity	0.69	0.66

The table shows that crushed coconut shell is comparable to sand in regard to sphericity and percentage loss after 100 hrs backwash. The porosity of shell is higher than that of sand and hence the head loss development is expected to be less in a shell media filter than in sand filter. Qualitative microscopic examination of the media grains showed that crushed coconut shell is more irregular in shape than sand grains and hence the surface area of the former will be higher than that of sand grains.

4.2 Phase 1 Determination of Filterability Numbers

Ives (1978) had proposed filterability number (F.N.) as a simple laboratory tool to obtain the optimum combination of filter media and suspension in terms of physical parameters like size and type of media, hydrodynamic parameters like filtration velocity and physicochemical characteristics of filter media and suspended particles which can be varied by coating the filter media with polyelectrolytes or providing different degrees of pretreatment to raw water. In the present investigation this concept has been utilised to obtain optimum combination of filter media-suspension before conducting conventional laboratory filtration runs. The parameters tried were different media sizes of sand and crushed coconut shell, different pretreatments and different filtration rates. The velocity gradients and flocculation times were also varied for direct filtration to obtain the maximum removal in the

succeeding treatment, i.e., filtration.

Filtration was carried out simultaneously through sand and crushed coconut shell media to compare the performance of the latter with that of sand. The summary of data collected from the first set of experiments on kaolinite clay suspension of initial turbidity 30-33 NTu is given in Table 4.2.

F.N. was calculated from the relation

$$F.N. = \frac{C}{C_o} \quad \frac{H}{Vt}$$

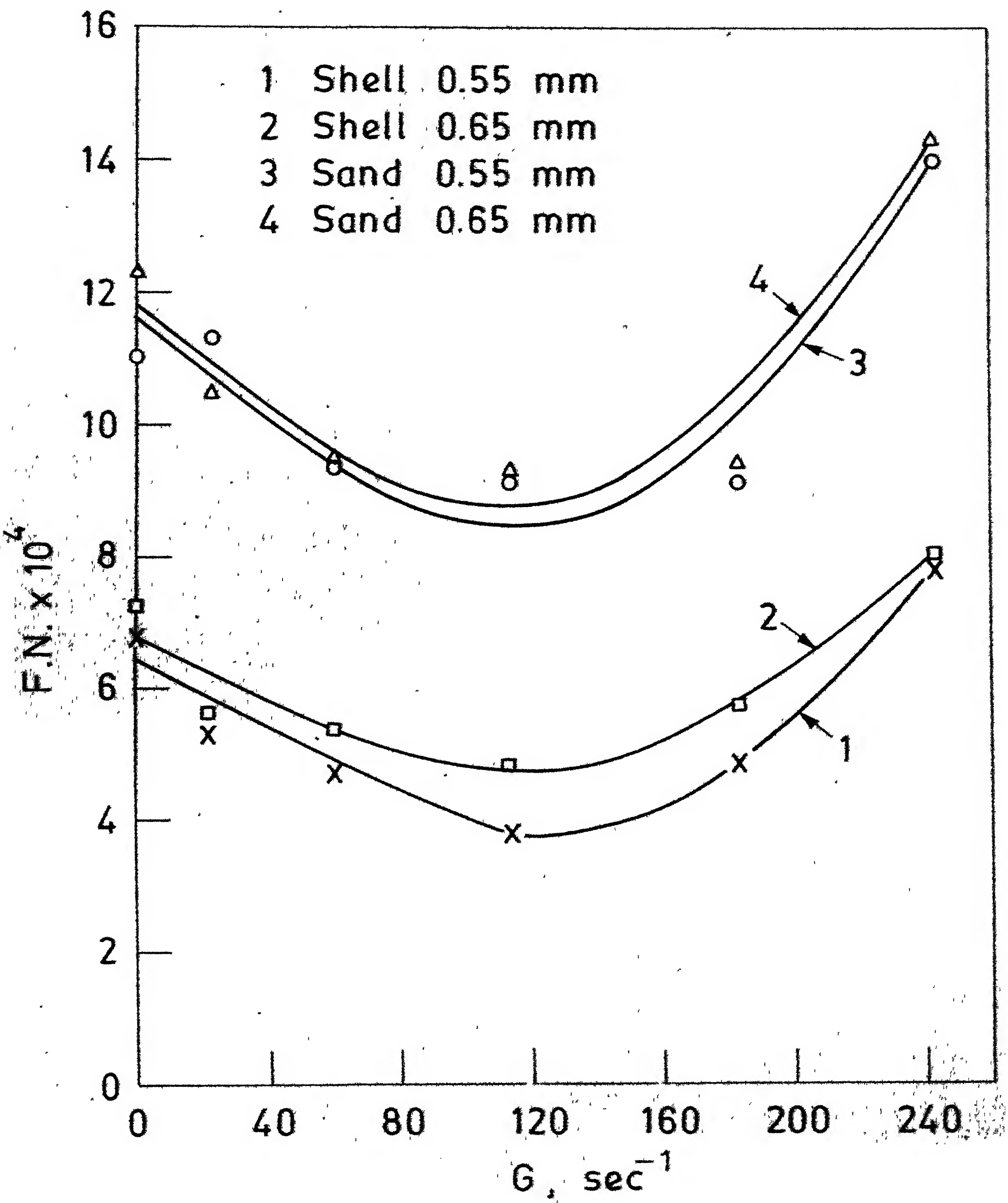
In all the experiments it was observed that the values of F.N. obtained for crushed coconut shell media-kaolinite combination were lower than these for sand-kaolinite combination. The head loss developed in the shell media was half or even less than that in sand bed. This low head loss development is attributed to the high porosity of the shell media. However, it was found that the effluent quality was not inferior to that from sand filter inspite of high porosity. On the other hand the effluent quality was better than or comparable to that obtained from sand bed. Hence it was suspected that some other removal mechanism like adsorption may also be operating in the removal of particles from the suspension.

Table 4.2 Comparison of F.N. for Sand and Shell

Grain size mm	Details of pretreatment: Alum dose mg/l	Details of pretreatment: Flocculation speed and time	Details of pretreatment: Sedimentation time	Residual turbidity NTu	Filterability Number F.N.: Sand	Filterability Number F.N.: Shell	Remarks
0.55	0	0	0	32	11.9×10^{-3}	5.1×10^{-3}	Raw water filtration
0.55	15	30 rpm, 20 min. (GT = 48,000)	0	33	2.3×10^{-3}	1.08×10^{-3}	Direct filtration
0.55	22	-do-	0	33	2×10^{-3}	9×10^{-4}	-do-
0.55	30	-do-	0	34	2.45×10^{-3}	9.2×10^{-4}	-do-
	30	-do-	20 min.	2.7	--	--	Conventional pretreatment (opt. Alum do
0.65	0	0	0	32	9.47×10^{-3}	3.24×10^{-3}	Raw water filtration
0.65	15	30 rpm, 20 min. (GT = 48,000)	0	32	2.1×10^{-3}	7.2×10^{-4}	Direct filtration.
0.65	22	-do-	0	33	1.75×10^{-3}	6.28×10^{-4}	-do-
0.65	30	-do-	0	33	1.94×10^{-3}	8.3×10^{-4}	-do-

The variation of F.N. with varying doses of alum clearly shows that there exists an optimum dose of alum required for direct filtration and this optimum dose is less than that required for conventional filtration. The optimum alum dose is 22 mg/l for direct filtration for two grain sizes of both sand and shell. An optimum coagulant dose of 30 mg/l had been obtained from jar tests for conventional filtration.

According to Treweek's (1979) observations, the optimum flocculation speed (velocity gradient) required for sedimentation is different from that required for optimum filtration. The velocity gradient applied for flocculation influences the characteristics like size and density of the flocs which in turn will affect filtration. Hence it was decided to conduct filtration tests to determine F.N. with pretreatment under varying GT values to optimise GT. The time of flocculation was kept constant and was 10 min. Fig. 4.1 shows the variation of F.N. with GT for sand and crushed coconut shell of G.M. size 0.55 mm and 0.65 mm. In all the four cases studied, an optimum GT value appeared to exist giving the lowest value of F.N. indicating best filterability. Values of G lower than this may not provide sufficient contacts for the turbid particles to form flocs whereas higher values of G may result in the shearing of flocs. In this set of experiments also crushed coconut shell media was found to



ig. 4.1 F.N. vs G value for sand and crushed coconut shell media.

give better performance than sand.

Filtration experiments were conducted at different rates of flow to determine the feasibility of high rate filtration with shell as the media.. The variation of F.N. with rate of flow is represented graphically in Fig. 4.2. The results indicate that high rates of filtration may not be feasible in sand bed, especially when the grain size is bigger. There was a steep increase in the F.N. in the case of sand-kaolinite combination when the filtration rate was increased from 7.2 $m^3/m^2/hr$ to 9.6 $m^3/m^2/hr$. This increase in F.N. was mainly due to the poor effluent quality observed. No considerable deterioration in effluent quality was observed in shell media even at the highest rate of flow 9.6 $m^3/m^2/hr$ tried. Hence crushed coconut shell media can be used for high rates of filtration also provided the development of head loss for longer duration is not uneconomically high.

4.3 Phase 2 - Column studies

Determination of F.N. will give only a preliminary information regarding the filterability of a suspension through a media. Column studies for longer duration are required for the quantitative determination of head loss development, service time, effluent quality deterioration, filter coefficient, attachment and removal efficiencies of media grains and clogging front development. In the present investigation column studies

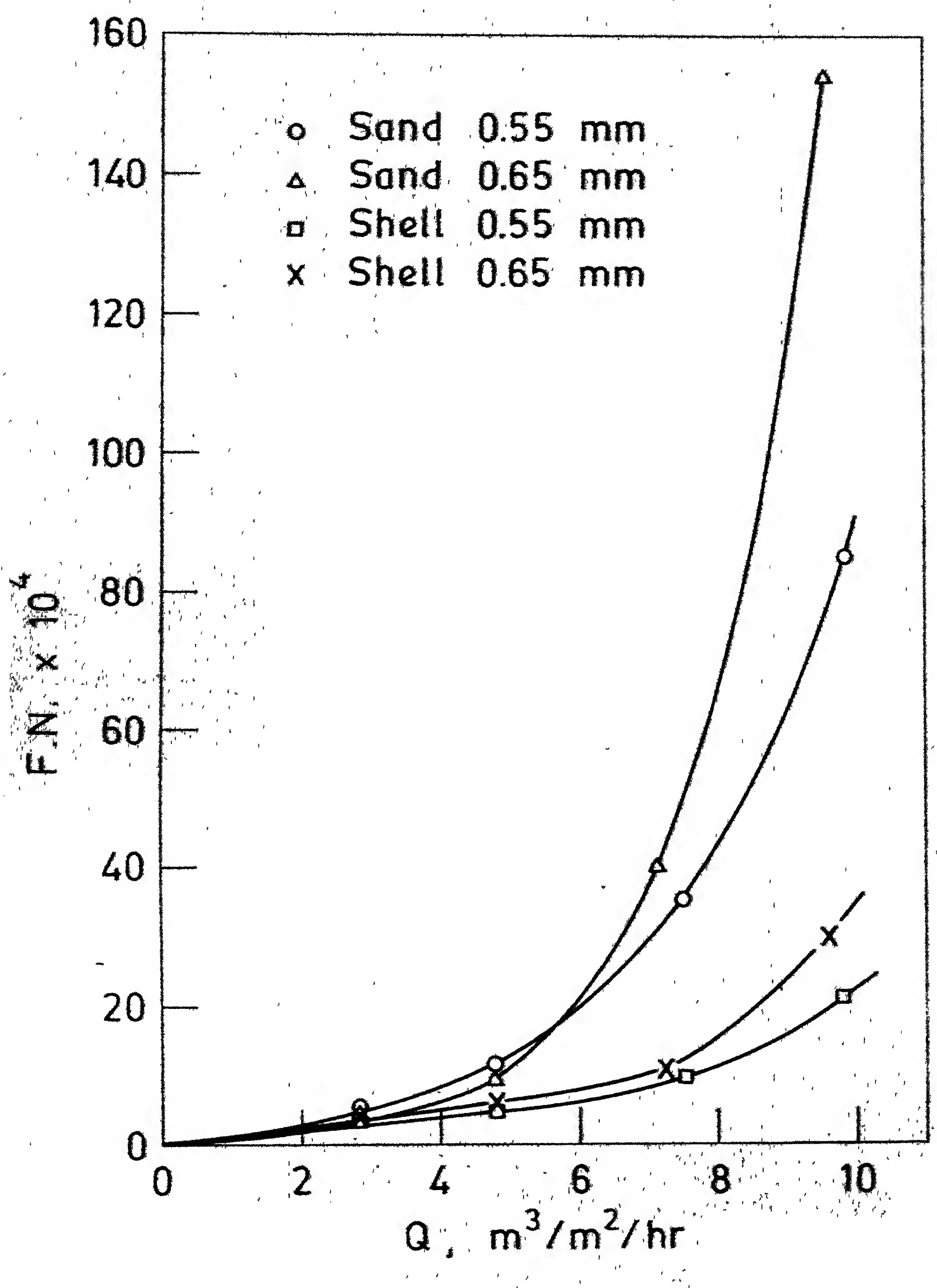
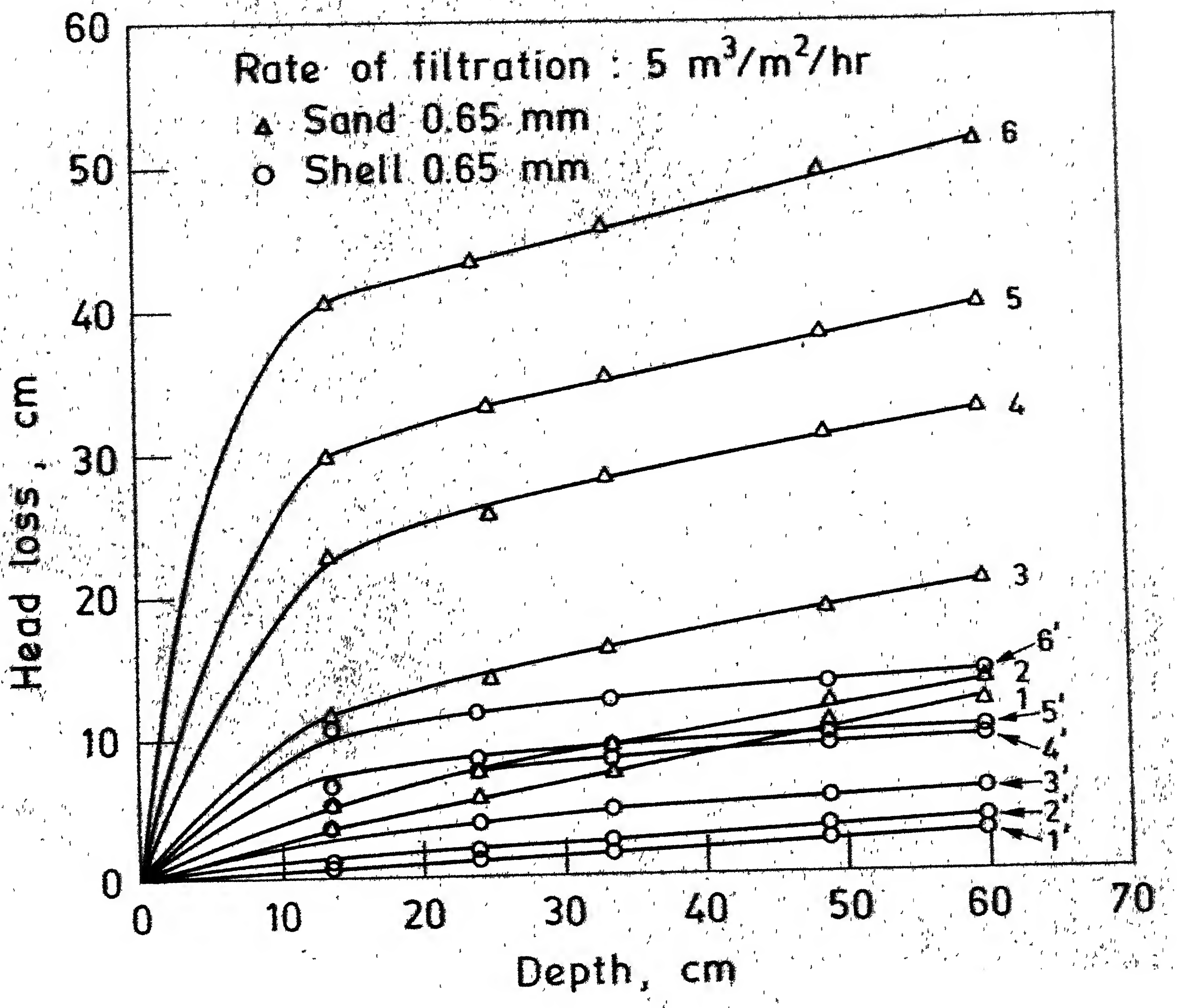


Fig. 4.2 - F.N. vs rate of filtration.

were conducted on raw water, settled water (conventional filtration) and direct filtration for estimating the above parameters. Results obtained in each case have been compared with those from sand filtration.

The variation of head loss with depth at different intervals of time is represented graphically in Fig.4.3 to 4.8 for raw water filtration, conventional filtration and direct filtration at the two rates of filtration viz. 5 and 7.5 $m^3/m^2/hr$. The head loss development was low in raw water filtration with turbidity removals of 80 to 88 percent. For rate of filtration of 5 $m^3/m^2/hr$, the effluent turbidity remained to be less than 5 NTu even after 22 hrs of filter run and the terminal head loss of 1 meter was not reached. Filtration at 7.5 $m^3/m^2/hr$ was carried out for 7 hr. only and the effluent quality remained within acceptable limit of 10 NTu recommended by the Environmental Hygiene Committee (1976). 60-70 percent of the removal was observed in the top 13.5 cm of the media below which the removal was rather uniform. The total head loss in crushed coconut shell media was less than 1/3rd of that in sand filter. As mentioned before, the higher porosity of crushed coconut shell aided in low head loss development in the media. Eventhough lower effluent quality was expected in the case of shell, the removal of turbidity was comparable to or even better than that in sand filtration. Hence raw water filtration may be adopted for moderately low turbid waters in rural areas.



Time, hrs

1 & 1' = 0.5
2 & 2' = 4.0
3 & 3' = 9.5
4 & 4' = 14.0
5 & 5' = 18.0
6 & 6' = 22.0

Fig. 4.3 – Head loss vs depth for raw water at different time intervals

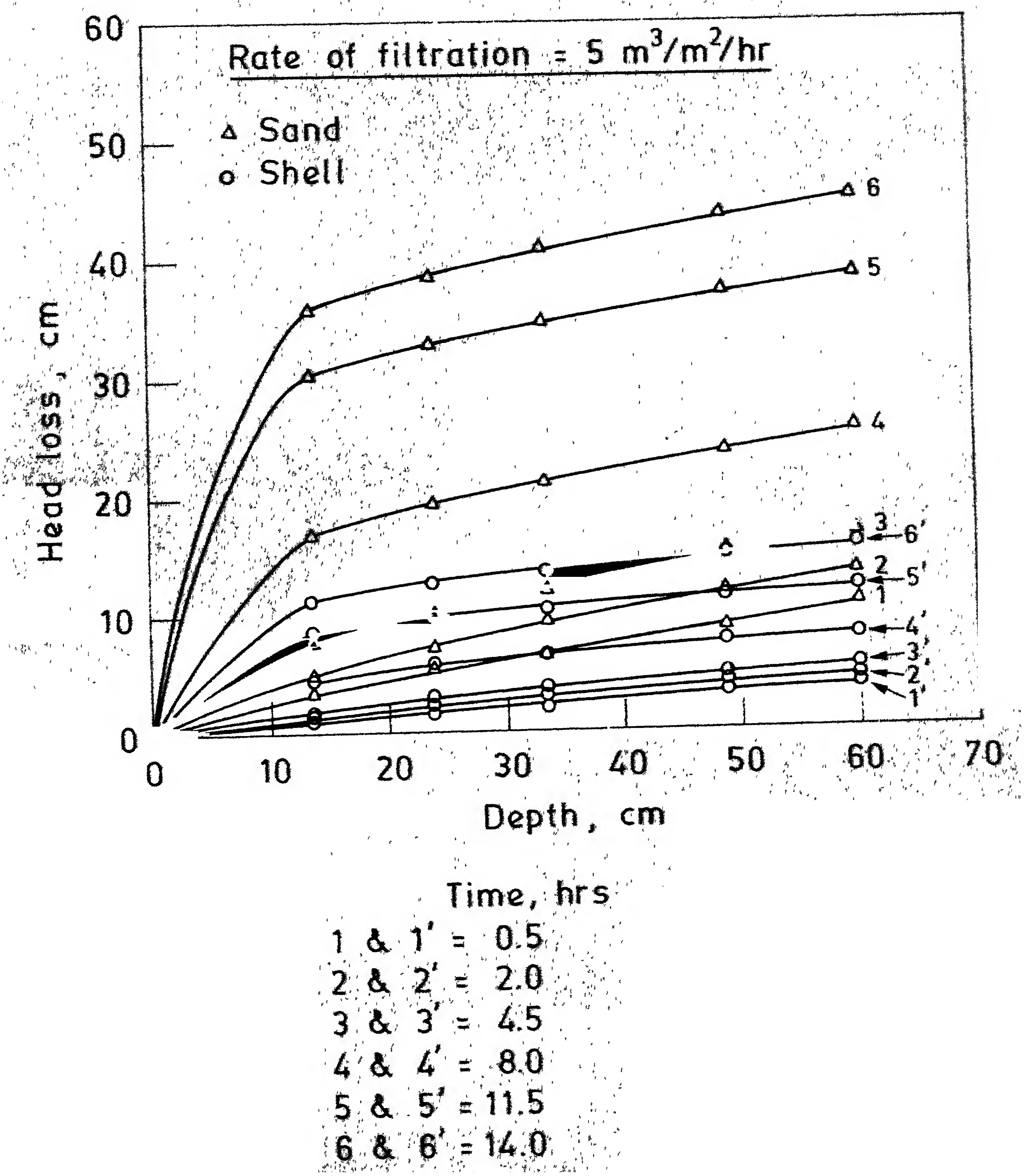


Fig. 4.4 - Head loss vs depth in conventional treatment at different time intervals

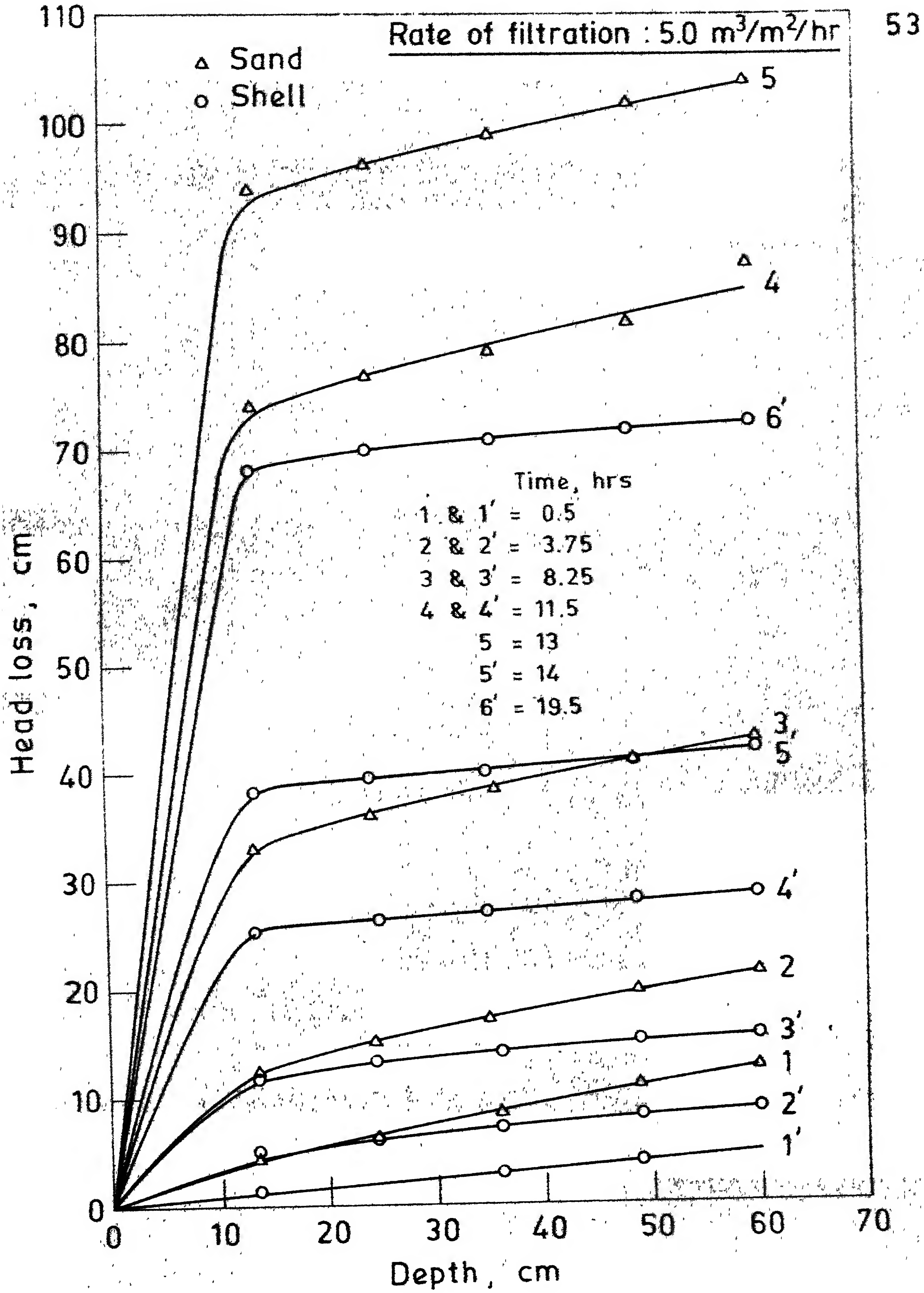


Fig. 4.5–Head loss vs depth for direct filtration at differen time intervals

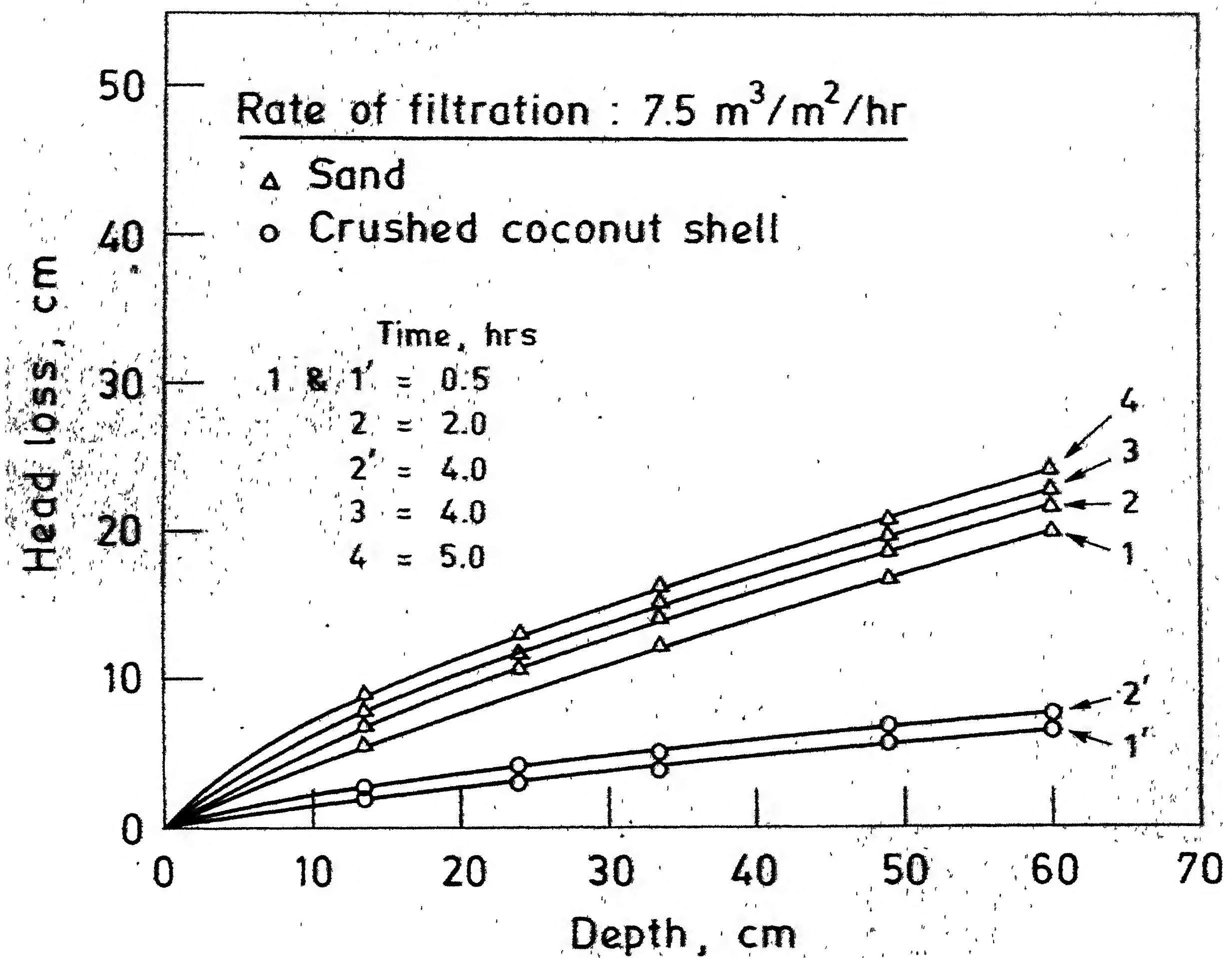


Fig. 4.6 - Head loss vs depth for raw water at different time intervals.

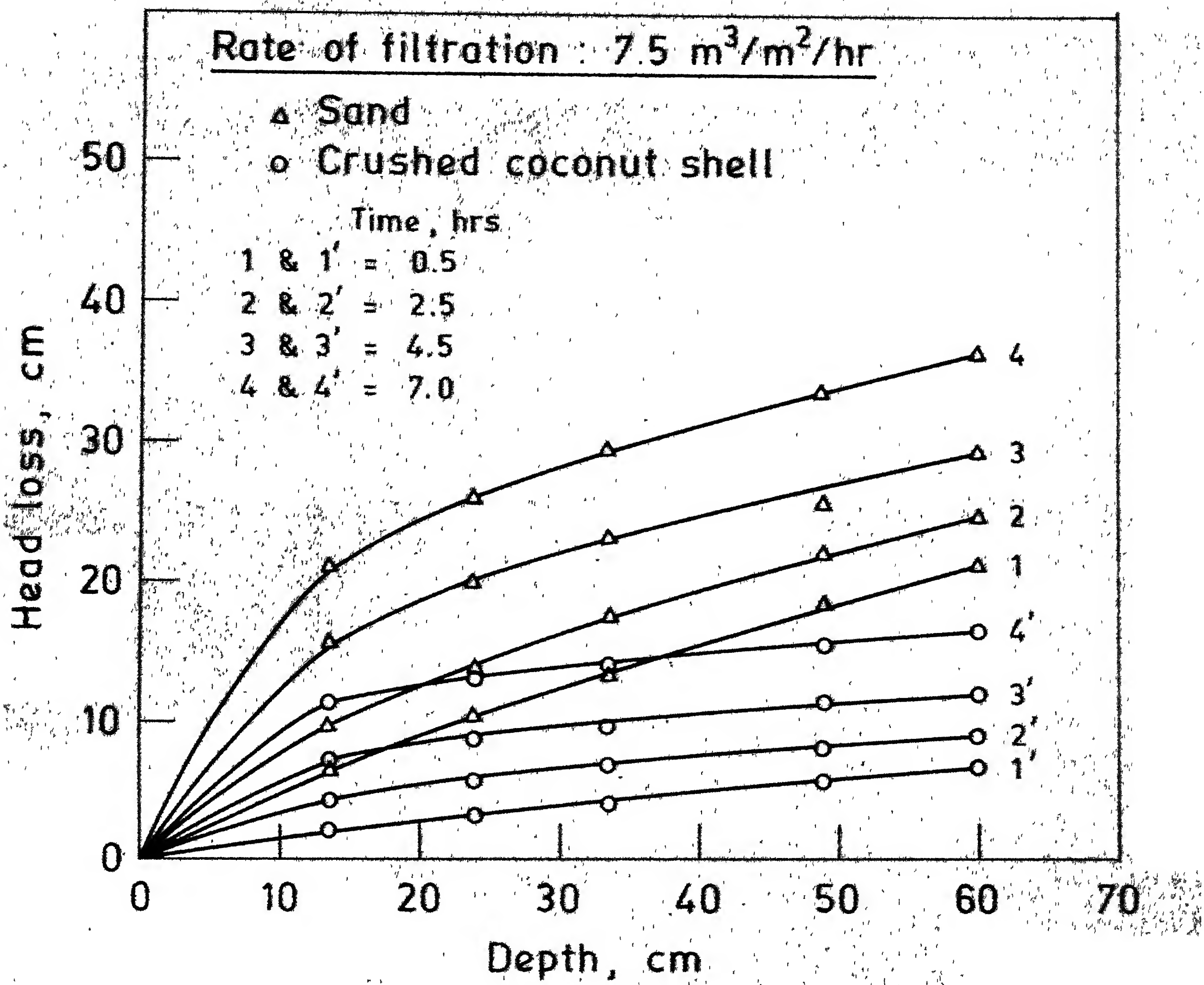
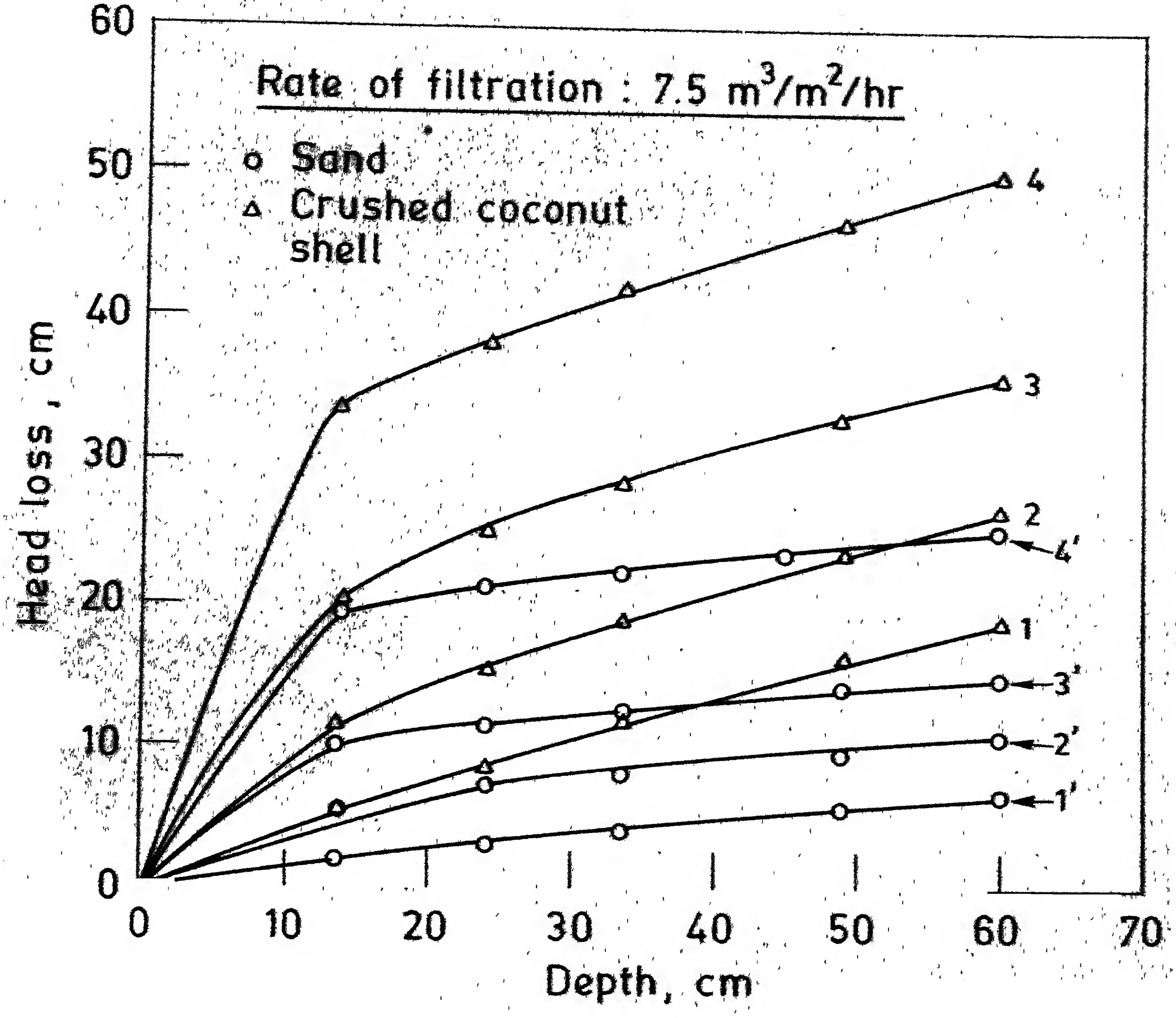


Fig. 4.7 - Head loss vs depth for conventional treatment.



Time, hrs

1 & 1' = 0.5

2 & 2' = 2.5

3 & 3' = 4.5

4 & 4' = 6.5

Fig. 4.8 – Head loss vs depth for direct filtration at different time intervals

Conventional filtration and direct filtration produced water with lower turbidities than that obtained from raw water filtration, but the head loss development was more rapid. The flocs are removed more easily than the untreated suspended particles as the change in surface characteristics of suspended particles brought about by flocculation enhance the attachment of particles to media grain or to already deposited particles acting as collectors. The higher rate of removal of particles in the bed induced higher head loss development due to the increase in surface area. This is in accordance with the theory O'Melia and Ali (1978). Effluent turbidity obtained from direct filtration was lower than that from conventional filtration and was less than 1 NTu throughout the duration of filter run which extended to 13 hr. in the case of sand filtration and 20.5 hr in crushed coconut shell media filtration. The reason for this could be higher influent concentration of particles than in conventional filtration which provided more retained particles as collectors and the desired floc characteristics required for optimum filtration. These led to much more rapid head loss development the case of direct filtration. The filter run at filtration rate of 5 $m^3/m^2/hr$ through sand bed was terminated after 13 hr on reaching the terminal head loss of .03 cm. However, filtration through coconut shell media was continued upto 20.5 hr even after which the total head loss (83 cm) was less than the terminal head loss

indicating the superiority of shell media to sand.

In all the experiments conducted the head loss build up was concentrated mainly in the top few cm indicating maximum removal from the top layer. The total head losses in crushed coconut shell media were found to be only one third to half of the corresponding values in sand filtration. In no case could a sharp and well defined clogging front be located which indicated that the zone of filtration was not clearly separated from the clean layers. This may be because the size of clay particles and flocs varied over a wide range and penetration of the same through the bed was not uniform. Adin and Rebhun (1974) reported that when alum was used as a coagulant, the working layer in the filter bed was broad and poorly defined and moved more rapidly than when a cationic polyelectrolyte was used as the coagulant.

Fig. 4.9 to 4.11 show the variation of initial filter coefficient λ_o with depth in both the beds at the filtration rates tried under different pretreatment conditions. λ_o values decreased with depth and most of the removal was observed at the top few cm of the bed. The process of filtration was found to be surface filtration rather than depth filtration. The variation in λ_o values for sand and crushed coconut shell media was comparatively small; but crushed coconut shell media showed higher λ_o values due to the slightly higher removal efficiency observed in the media. The variation of filter coefficient (λ)

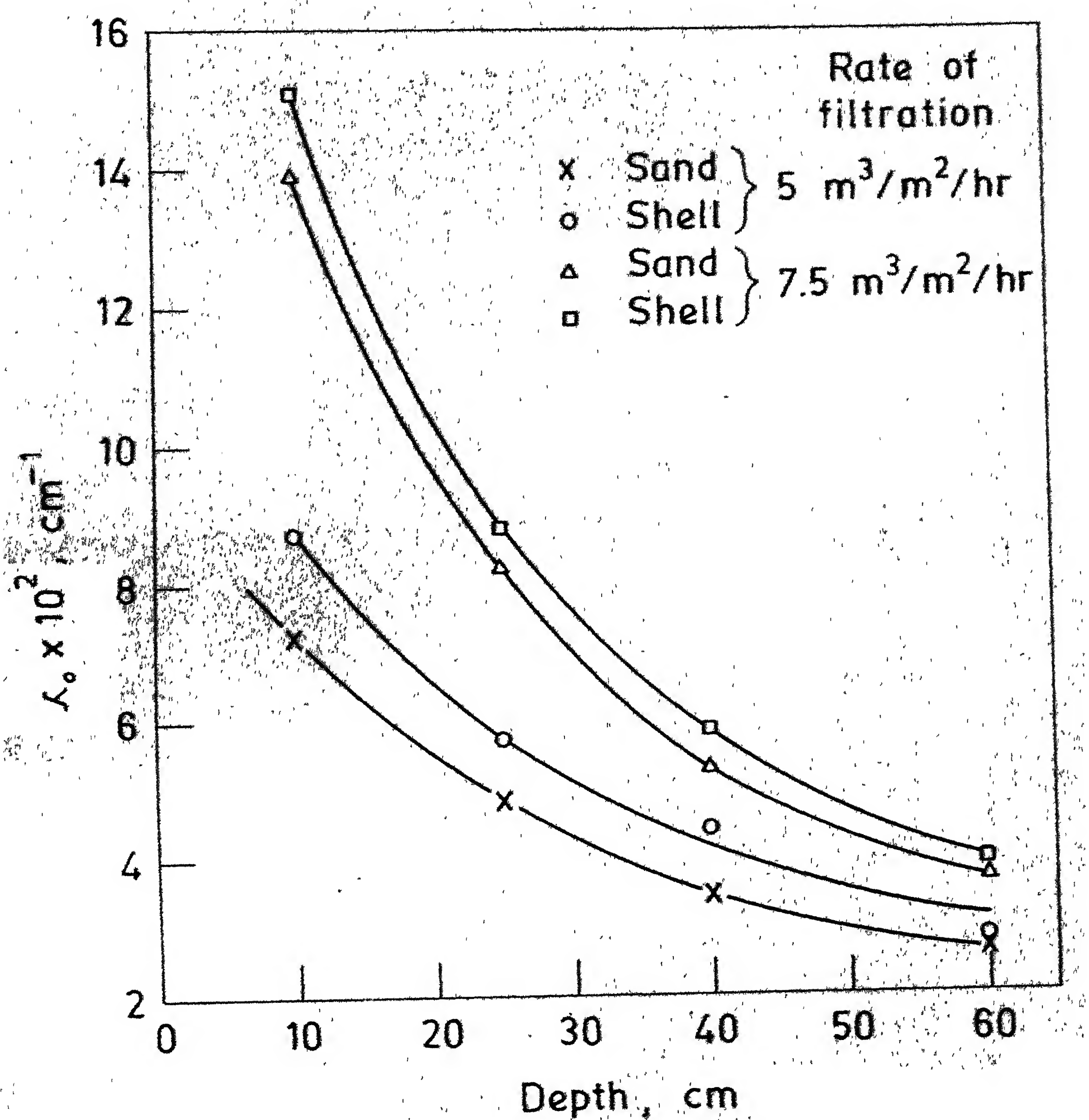


Fig. 4.9 – λ_o vs depth for raw water.

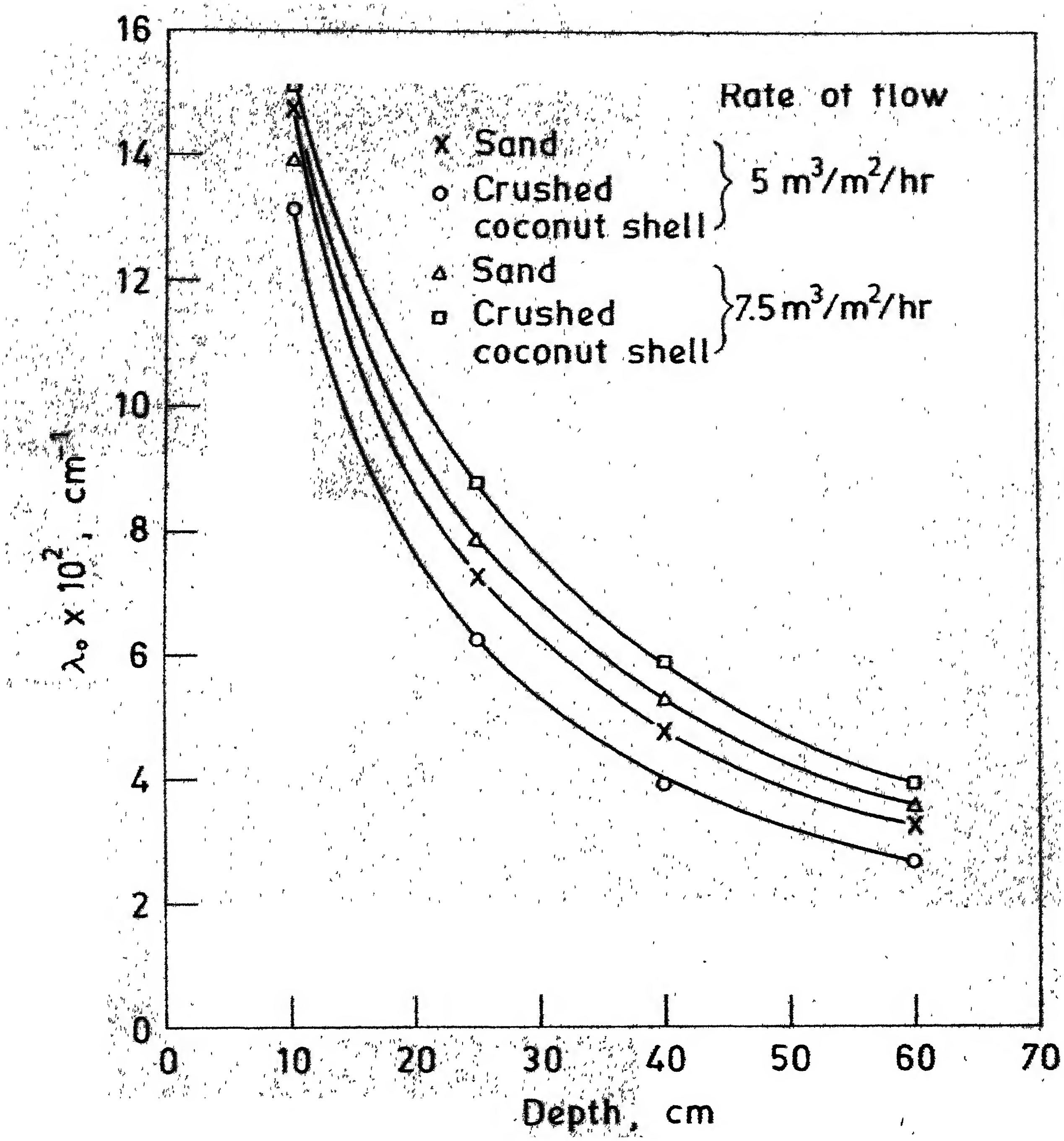


Fig. 4.10 - λ_o vs depth for conventional treatment.

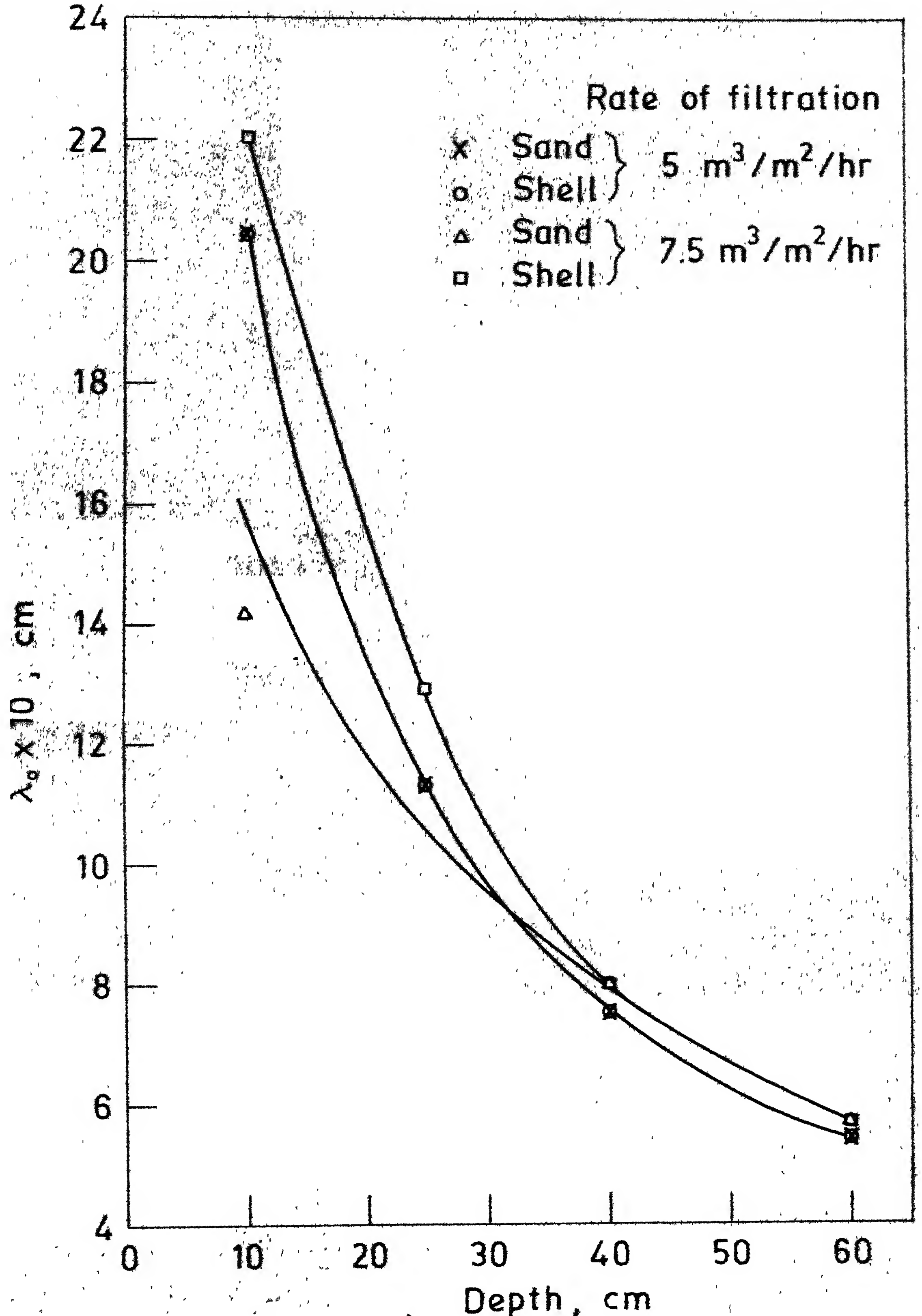


Fig. 4.11 - λ_o vs depth for direct filtration.

with time (Fig.4.12 to 4.16) showed different trends for different flow rates and under different pretreatment conditions. It is evident from Fig.4.12 that the λ values at a depth of 13.5 cm from the surface of the media for raw water filtration at the rate of 5 $m^3/m^2/hr$ showed improvement with time except for an initial degradation in the case of sand filtration. This initial degradation may be due to some turbid particles remaining in the bed even after backwash. However, this behaviour was not observed in subsequent experiments. As the filtration rate was increased to 7.5 $m^3/m^2/hr$, the λ values showed a reduction with time even at deeper layers (Fig.4.13) for both sand and shell media filter. However, λ increased for both filters at a depth of 60 cm. This means that in the upper layers the particle- to-media and particle-to-particle contacts were not sufficient to improve removal efficiency. The λ values for conventional filtration (Fig.4.14) showed improvement with time for both the media for both the filtration rates. λ for direct filtration presented in Fig.4.15 and 4.16 showed reduction with time of filtration at the highest port (at 13.5 cm from the surface of the media) but showed improvement at 24 cm from the surface for a rate of filtration of 5 $m^3/m^2/hr$ and at 33.5 cm for a rate of filtration of 7.5 $m^3/m^2/hr$ for both sand and shell media. The quality of filtered water in sand bed at a depth of 24 cm started deteriorating after about 4.5 hr for a filtration rate of 5 $m^3/m^2/hr$ while that from shell filter did not show any such deterioration throughout the duration of the experiment (20.5 hr).

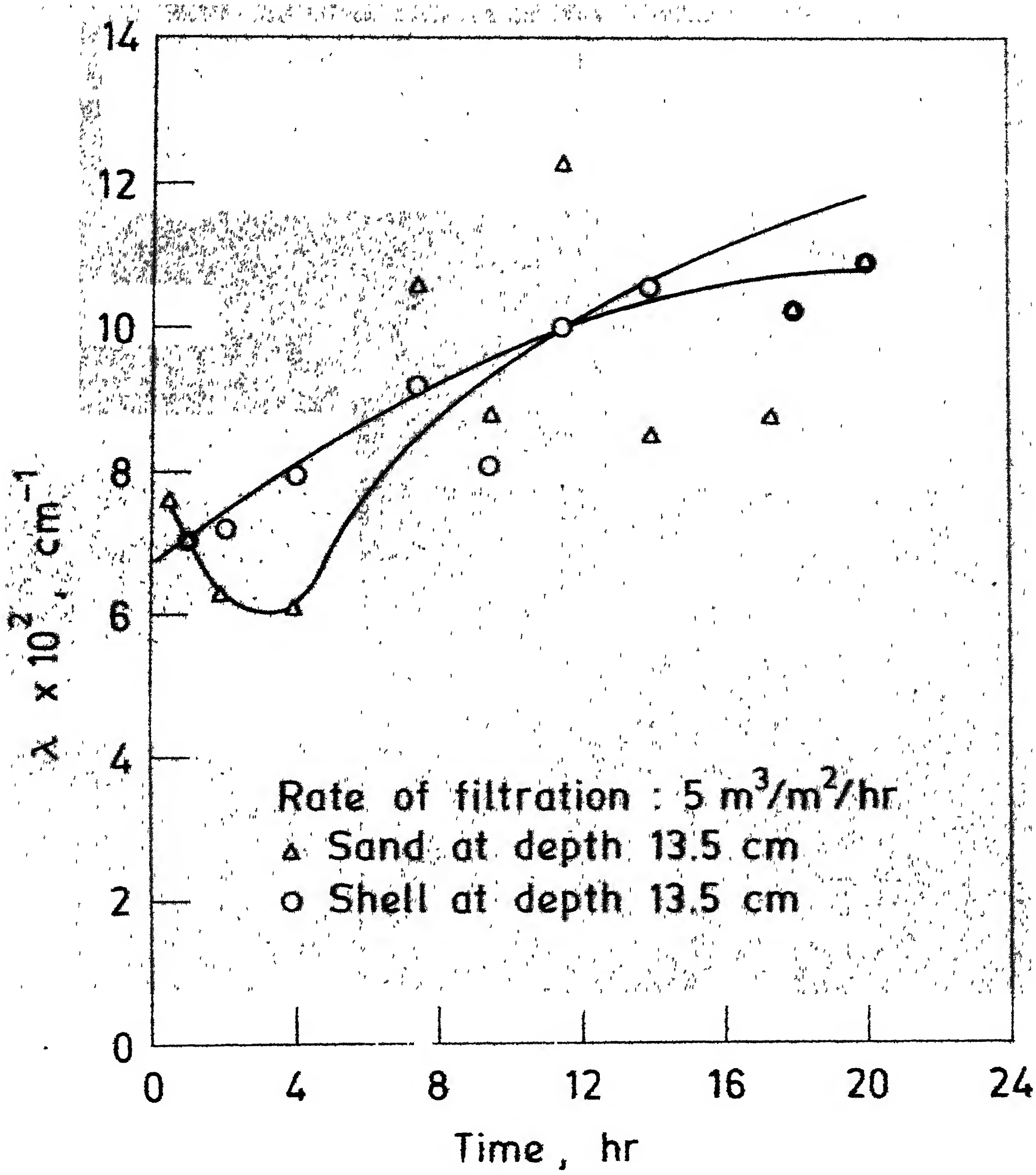


Fig. 4.12- λ vs time for raw water.

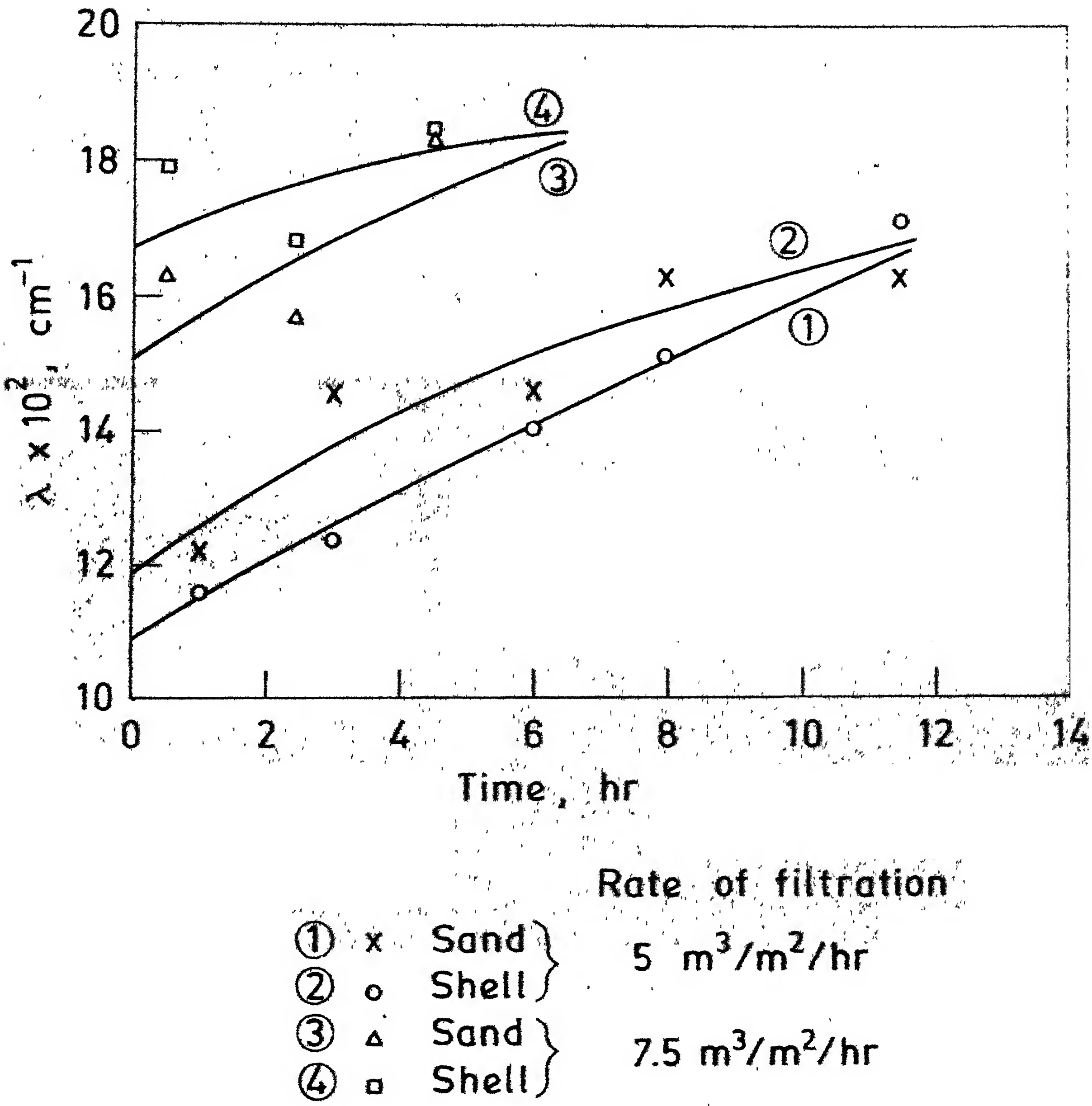


Fig. 4.13 - λ vs time for conventional treatment at 13.5 cm from the surface of the media

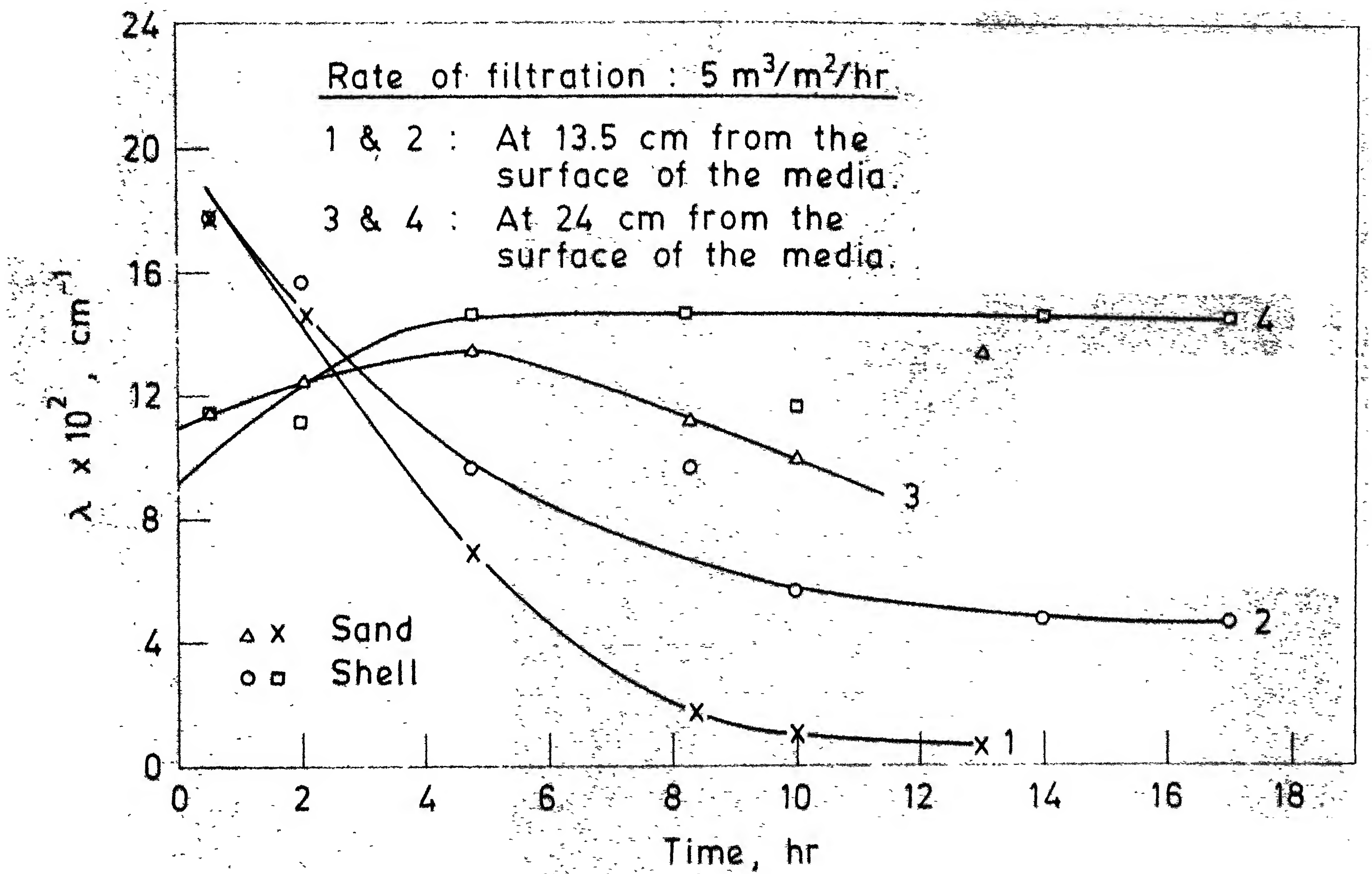
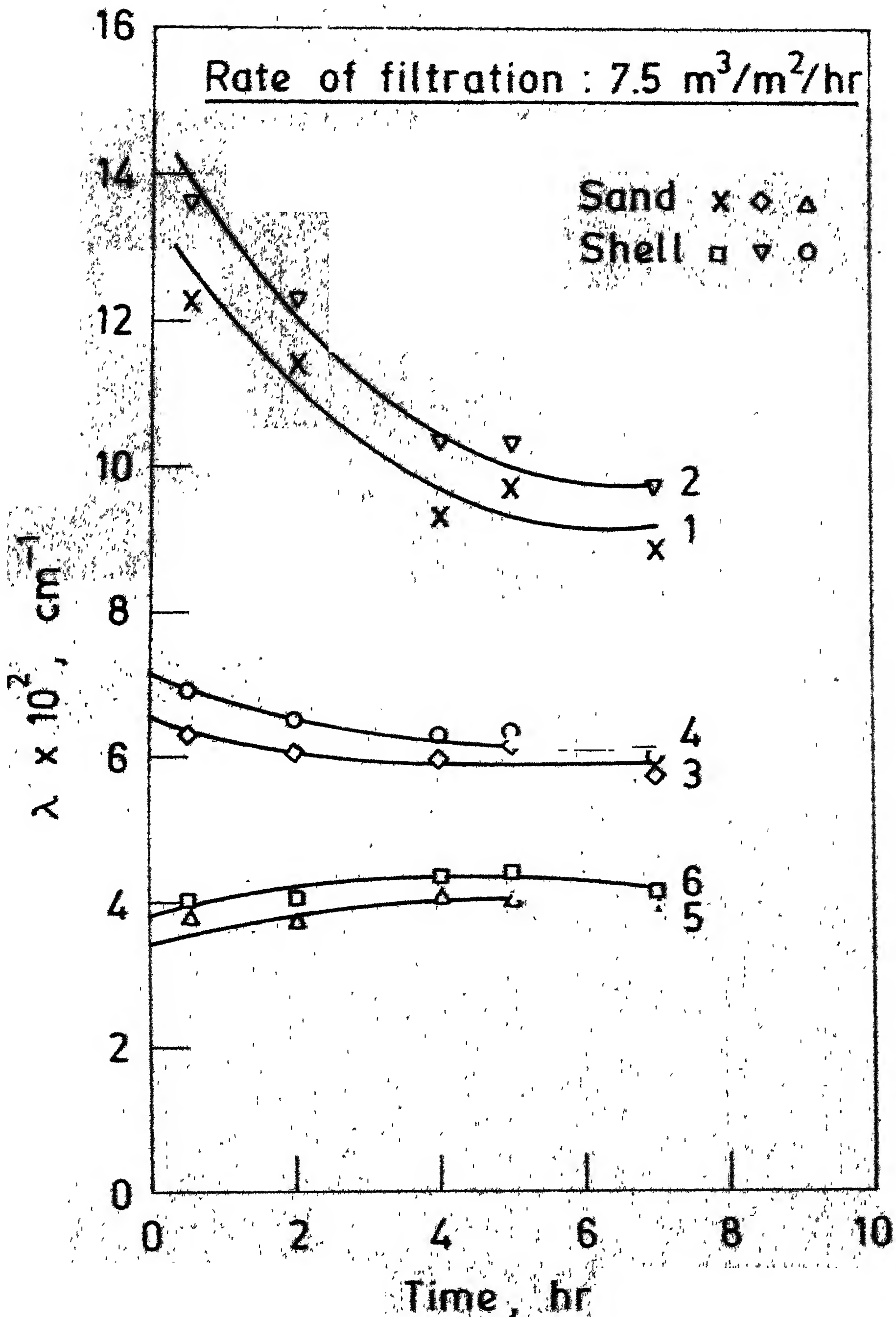
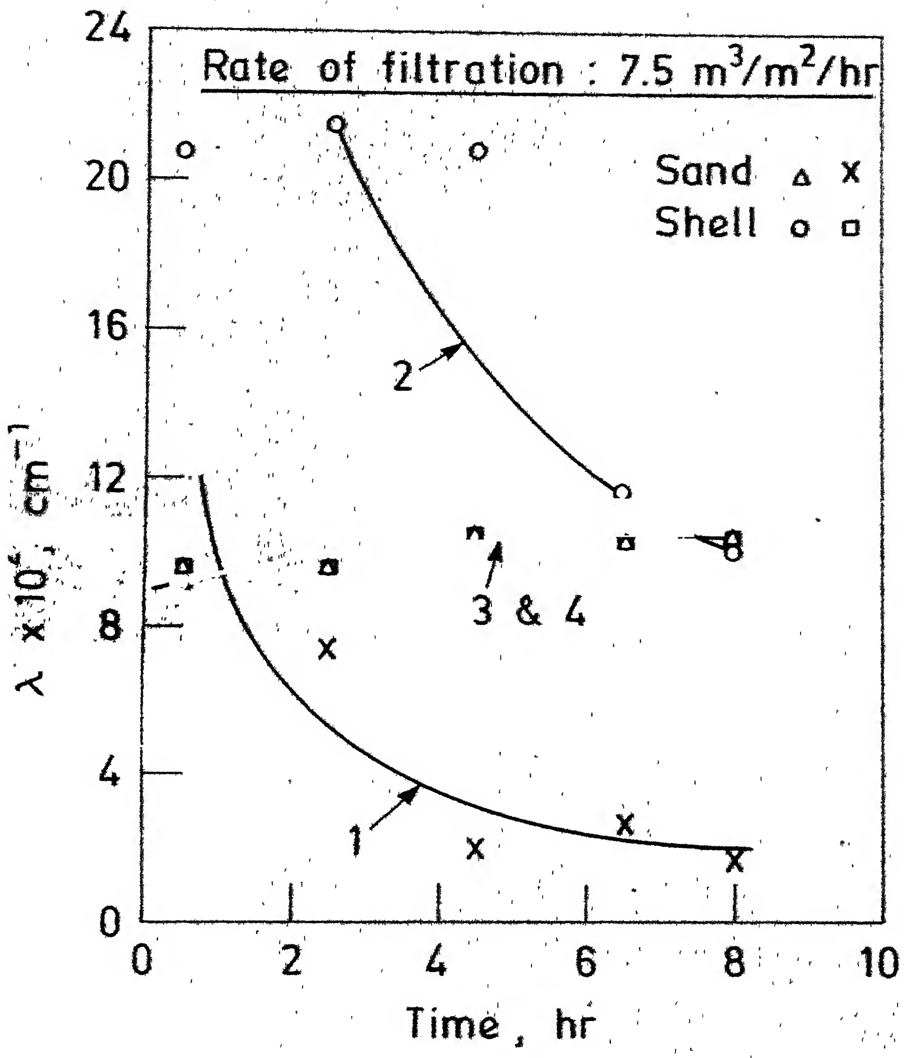


Fig. 4.14- λ vs time for direct filtration.



1 & 2 - At depth 13.5 cm
3 & 4 - At depth 33.5 cm
5 & 6 - At depth 60.0 cm

Fig. 4.15 - λ vs time for raw water.



1 & 2 : At 13.5 cm from the surface of the media.
3 & 4 : At 33.5 cm from the surface of the media.

Fig. 4.16 - λ vs time for direct filtration.

The λ values for a filtration rate of 7.5 $m^3/m^2/hr$ under all the three pretreatment conditions were higher than the corresponding values for a filtration rate of 5 $m^3/m^2/hr$. The higher velocity of water through the media enhanced contacts between both particles and media and particles and particles thus giving rise to higher removal efficiency. In coagulation and flocculation increase in velocity gradient to some extent enahances the settling of flocs by providing more contact opportunities between the suspended particles thus rendering the formation of bigger flocs. But very highv velocity gradients impair the settling by shearing the flocs already formed. Considering the analogy between coagulation-flocculation and filtration, the higher rate of filtration tried in the present investigation might have induced higher velocity gradients providing more contact opportunities between particle and media grain and particle and deposited particles acting as collectors. Still higher rates of filtration may reduce the efficiency of removal of particles due to lesser contact time and shearing of the deposited particles. This aspect was not studied in the present investigation.

The λ values for filtration through crushed coconut shell media were always higher than those for sand except in conventional filtration at a rate of 5 $m^3/m^2/hr$. The reason for the lower removal efficiency observed in this is not known.

The combined values of transport efficiency and attachment coefficient were determined for the different pretreatment conditions from Yao's equation (1971) for filter coefficient

$$\lambda_o = 1.5 \frac{(1 - f)}{d_m} (\eta\alpha)$$

where λ_o is the filter coefficient for a clean filter bed,

f is the clean bed porosity

d_m is the diameter of media grain,

η is the total transport efficiency and

α is the attachment coefficient.

Table 4.3 gives the values of $(\eta\alpha)$ for both the media under the different pretreatment conditions and flow rates studied.

It was observed that pretreatments improved the value of $(\eta\alpha)$ and the highest values were observed in direct filtration. Transport efficiency (η) is a function of the diameter (d_p) of the suspended particle where as attachment coefficient (α) is influenced by pretreatment which changes the characteristics of the particles. Concentration of particles (Co) also affects removal efficiency. In raw water filtration (Co) was high, but d_p was low and pretreatment was absent. Hence the values of η and α were low. In conventional filtration eventhough Co was low and d_p was also low due to

Table 4.3 ($\eta\alpha$) Values for Sand and Crushed Coconut Shell Media

Media	Rate of filtration $m^3/m^2/hr$	($\eta\alpha$) Raw water filtration	Conventional filtration	Direct filtration	Remarks
Sand	5	.0054	.011	.015	Direct filtration is better
Sand	7.5	.010	.011	.012	All three are almost same.
Crushed coconut	5	.010	.017	.023	Direct filtration is better
Shell	7.5	.017	.017	.024	Direct filtration is better

sedimentation of bigger flocs, α was higher which gave higher ($\eta\alpha$) values than in raw water filtration. Direct filtration provided the best result as Co and d_p were higher due to absence of sedimentation and pretreatment yielded better attachment of particles. Hence ($\eta\alpha$) values were higher in direct filtration than in conventional filtration.

4.4 Mode of action of sand and crushed coconut shell filter

As the porosity of crushed coconut shell media was higher the head loss and effluent quality in shell filter had been expected to be lower than those in sand filter. But the experiments conducted in phase 1 and 2 clearly indicate that shell is superior to sand as a filter media as the head losses in shell bed were roughly one third of that in sand bed and the effluent quality was comparable to or even better than that from sand bed.

As an explanation it was first contemplated that the pores in the shell grains trapped a fraction of the suspended particles with size smaller than the pores thus leading to removal of the same without inducing any head loss while the attachment of bigger particles on to the surface of the grains gave rise to head loss development. No such pore diffusion would take place in sand grains and hence the head loss would be higher for the same effluent quality. To check the extent of adsorption batch sorption experiments were conducted on shell

and sand grains using clay and protein solution like albumin. The results of the experiments showed that adsorption was not occuring on either sand or shell. However the conditions in the batch study do not represent those in a filter column and hence the test is not very reliable. Again to check whether adsorption played any significant role in the removal of particles filter runs were performed with raw turbid water after backwashing the bed (Table 4.3). If pore diffusion had been an operating mechanism, the performance of the bed in terms of removal efficiency and head loss development would have been less effective as particles already present in the pores would reduce the capacity of the same to retain particles. But the performance of the bed after backwash followed the same trend as in the previous case. Hence it was concluded that either adsorption was not an operating mechanism in the removal of particles in a crushed coconut shell bed or if adsorption took place in the pores, the capacity of the pores to retain particles was not exhausted.

It is also felt that the better performance of shell media filter may be because the pore sizes of the media are small enough to trap the particles eventhough the porosity is high. However, extensive studies are required to arrive at any conclusion regarding the removal mechanism.

Table 4.4 Head loss and Turbidity Removal for Raw Water Filtration after Backwash

Time hr	Head loss						Effluent Turbidity C					
	Sand			Shell			Sand			Shell		
	d 13.5 cm	d 33.5 cm	d 60 cm	d 13.5 cm	d 33.5 cm	d 60 cm	d 13.5 cm	d 33.5 cm	d 60 cm	d 13.5 cm	d 33.5 cm	d 60 cm
0.5	3.5	8.0	12.0	.8	1.9	3.0	7.5	5.5	3.0	5.5	4.5	2.5
1.75	3.8	8.1	12.5	1	2.1	3.5	6.4	3.2	3.2	3.8	2.5	1.7
3.75	4.8	8.9	12.7	1.1	2.3	3.9	8.2	5.6	3.4	6.2	4.8	3.3
5.75	8.2	12.0	15.2	1.7	3.1	4.7	5.8	3.3	3.3	4.5	3.5	2.7
8	10.1	14.3	18.0	2.1	3.5	5.1	6.0	3.3	3.0	5.0	3.8	2.7

d is depth of media from the surface of the bed.

5. SUMMARY AND CONCLUSIONS

Filtration studies were conducted using kaolinite suspension to evaluate the potentiality of crushed coconut shell as a filter media under different pretreatment conditions and at different filtration rates. The concept of filterability number was used for the preliminary screening tests to obtain optimum combinations of media-suspension characteristics, degree of pretreatment and filtration rates. Conclusions arrived at from the above tests were applied in the conventional column studies on filtration conducted for longer durations. An attempt was made to determine qualitatively the mechanism of removal of suspended particles in a crushed shell media which rendered it more effective than the sand media.

The following conclusions were arrived at from the present investigations:

1. Crushed coconut shell shows better performance than sand as a filter media in raw water, conventional and direct filtration of clay suspension of moderately low turbidity.
2. Raw water filtration of moderately low turbid water produces effluent of acceptable quality (less than 5 NTu) with comparatively low head loss development.

3. Direct filtration (coagulation, flocculation and filtration) using single media filters with crushed coconut shell as the filter media is a feasible proposition for treating moderately turbid water.
4. Higher rates of filtration are possible when crushed coconut shell is used as the filter media.
5. There exists an optimum range of GT value which gives the best performance in direct filtration.
6. Values of ($\eta\alpha$) show improvement with pretreatment, direct filtration at optimum GT giving the highest values.

6. ENGINEERING SIGNIFICANCE AND SUGGESTIONS FOR FURTHER WORK

The present investigation showed that crushed coconut shell can be used as a media in single media filters for conventional and direct filtration. Where coconut shells are available at a reasonable cost, the adoption of the same may be advisable due to the longer service time achieved. By adopting direct filtration, conventional sedimentation tanks can be eliminated and reduction in alum dose achieved. As higher rates of filtration reduce the cost of treatment, crushed coconut shell may, in the long run prove more economical than sand as a filter media.

The following aspects need further investigations.

1. The mechanism of removal in filtration through crushed coconut shell media filter which is responsible for the better performance of a shell media filter than a sand filter.

2. Leaching of organic compounds in the effluent from the shell filter.

3. Influence of optimum pretreatment conditions in direct filtration on the removal mechanism.

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